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ORBITAL TRANSFER VEHICLE CONCEPT DEFINITION AND SYSTEM ANALYSIS STUDY

Final Report Volume IX

IMPLICATIONS OF ALTERNATIVE MISSION MODELS AND LAUNCH VEHICLES

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By
Boeing Aerospace Company

Seattle, Washington 98124

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FOREWORD

This final report of the Orbital Transfer Vehicle (OTV) Concept Definition and System Analysis Study was prepared by Boeing Aerospace Company for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-36107. The study was conducted under the direction of the NASA OTV Study Manager, Mr. Donald Saxton, during the period from August 1984 to September 1986.

This final report is organized into the following nine documents:

VOL. I	Executive Summary (Rev. A)
VOL. II	OTV Concept Definition and Evaluation
	Book 1 - Mission Analysis and System Requirements
	Book 2 - OTV Concept Definition
	Book 3 - Subsystem Trade Studies
	Book 4 - Operations and Propellant Logistics
VOL. III	System & Program Trades
VOL. IV	Space Station Accommodations
VOL. V	WBS & Dictionary
VOL. VI	Cost Estimates
VOL. VII	Integrated Technology Development Plan
VOL. VIII	Environmental Analysis
VOL. IX	Implications of Alternate Mission Models
	and Launch Vehicles

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ACRONYMS AND ABBREVIATIONS

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A/A Aeroassist

ACC Aft Cargo Carrier

AFE Aeroassist Flight Experiment

AGE Aerospace Ground Equipment

AL Aluminum

ASE Airborne Support Equipment

A/T Acceptance Test, Auxiliary Tank

AUX Auxiliary
AVG Average

B/B Ballute Brake

B/W Backwall

CDR Critical Design Review
CLV Cargo Launch Vehicle
CPU Central Processing Unit

CUM Cumulative

DAK Double Aluminized Kapton

DDT&E Design, Development, Test & Evaluation

DELIV Delivery

DMS Data Management System

DMU Data Management Unit

DoD Department of Defense

EOM End of Mission

EPS Electrical Power System

FACIL Facility

FFC First Flight Certification

FLTS Flights

FOSR Flexible Optical Surface Reflector
FRCI Fiber Refractory Composite Insulation

FRS Fully Reusable System

F.S. Fail Safe

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FSI Flexible Surface Insulation

FTA Facilities Test Article

GB Ground Based

GEO Geostationary Earth Orbit

GOCM Ground Operations Cost Model

GPS Global Positioning System

GRIEP Graphite Epoxy

GRD Ground

IOC Initial Operational Capability
IMU Inertial Measurement Unit
IRU Inertial Reference Unit

IUS Inertial Upper Stage

JSC Johnson Space Center

KBS Knowledge Base System

L/B Lifting Brake
LCC Life Cycle Cost

LCC Launch Control Center

L/D Lift to Drag

MCS Mission Control System

MGSS Mobile GEO Service Station

MLI Multilayer Insulation
MPS Main Propulsion System

MPTA Main Propulsion Test Article

MSFC Marshall Space Flight Center

Only Orbital Managements Valida

OMV Orbital Maneuvering Vehicle

OPS Operations

OTV Orbital Transfer Vehicle

P/A Propulsion/Avionics

PAM Payload Assist Module, Propulsion Avionics Module

PDR Preliminary Design Review

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PFC Preliminary Flight Certification

P/L Payload

PIP Payload Integration Plan

PROD Production
PROP Propellant

PRS Partially Reusable System

RCS Reaction Control System

REF Reference

RGB Reusable Ground Based

R&R Remove & Replace

RSB Reusable Space Based

RSI Reusable Surface Insulation

SB Space Based

S/C Spacecraft

SCB Shuttle Cargo Bay

SIL Systems Integration Laboratory

STA Structural Test Article

STG Stage

STS Space Transportation System

T/D Turndown

TDRS Tracking Data Relay Satellite

TFU Theoretical First Unit

TPS Thermal Protection System

TT&C Telemetry, Tracking and Control

WBS Work Breakdown Structure

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1.0 INTRODUCTION

This section provides a description of the study in terms of background, objectives, issues, organization of study and report, and the content of this specific volume.

Use of trade names, names of manufacturers, or recommendations in this report does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

And finally, it should be recognized that this study was conducted prior to the STS safety review that resulted in an STS position of "no Centaur in Shuttle" and subsequently an indication of no plans to accommodate a cryo OTV or OTV propellant dump/vent. The implications of this decision are briefly addressed in section 2.2 of the Volume I and also in Volume IX reporting the Phase II effort which had the OTV launched by an unmanned cargo launch vehicle. A full assessment of a safety compatible cryo OTV launched by the Shuttle will require analysis in a future study.

1.1 BACKGROUND

Access to GEO and earth escape capability is currently achieved through the use of partially reusable and expendable launch systems and expendable upper stages. Projected mission requirements beyond the mid-1990's indicate durations and payload characteristics in terms of mass and nature (manned missions) that will exceed the capabilities of the existing upper stage fleet. Equally important as the physical shortfalls is the relatively high cost to the payload. Based on STS launch and existing upper stages, the cost of delivering payloads to GEO range from \$12,000 to \$24,000 per pound.

A significant step in overcoming the above factors would be the development of a new highly efficient upper stage. Numerous studies (ref. 1, 2, 3, 4) have been conducted during the past decade concerning the definition of such a stage and its program. The scope of these investigations have included a wide variety of system-level issues dealing with reusability, the type of propulsion to be used, benefits of aeroassist, ground- and space-basing, and impact of the launch system.

1.2 OBJECTIVES AND ISSUES

The overall objective of this study was to re-examine many of these same issues but within the framework of the most recent projections in technology readiness, realization that Space Station is a firm national commitment, and a refinement in mission projections out to 2010.

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During the nineteen-month technical effort the specific issues addressed were:

- a. What are the driving missions?
- b. What are the preferred space-based OTV characteristics in terms of propulsion, aeroassist, staging, and operability features?
- c. What are the preferred ground-based OTV characteristics in terms of delivery mode, aeroassist, and ability to satisfy the most demanding missions?
- d. How extensive are the orbital support systems in terms of propellant logistics and Space Station accommodations?
- e. Where should the OTV be based?
- f. How cost effective is a reusable OTV program?
- g. What are the implications of using advanced launch vehicles?

1.3 STUDY AND REPORT ORGANIZATION

Accomplishment of the objectives and investigation of the issues was done considering two basic combinations of mission models and launch systems. Phase I concerned itself with a mission model having 145 OTV flights during the 1995-2010 timeframe (Revision 8 OTV Mission Model) and relied solely on the Space Shuttle for launching. Phase 2 considered a more ambitious model (Rev. 9) having 442 flights during the same time frame as well as use of a large unmanned cargo launch vehicle and an advanced Space Shuttle (STS II).

The study is reported in nine separate volumes. Volume I presents an overview of the results and findings for the entire study. Volume II through VIII contains material associated only with the Phase I activity. Volume IX presents material unique to the Phase II activity. Phase I involved five quarters of the technical effort and one quarter was associated with the Phase II analyses.

1.4 PHASE II OVERVIEW

Essentially all technical areas of an OTV program are impacted when a large unmanned cargo launch vehicle is employed and more demanding missions (relative to Phase I) are to be accomplished. The anticipated result of these impacts is that the preferred OTV concept in terms of degree of reusability will be heavily influenced by the launch system not having cargo return to Earth capability and the mission model being composed primarily of relatively heavy one way payloads.

A description of the content of this specific document, the analyses approach and key study groundrules follows.

1.4.1 Document Content

This document reports all work associated with the Phase II activity addressing implications of advanced launch systems and more demanding mission models to an OTV program. The top level transportation requirements resulting from the Rev. 9.. Mission Model are defined in the mission analysis section. The OTV concepts section addresses the configuration and flight operations impacts in terms of sizing and degree of reusability. An aeroassist analysis section is provided to address guidance and aerothermal issues associated with an aeroassist device not previously analyzed. Orbital support needs primarily focus on the capacity of the propellant logistics system. The launch operations section defines the OTV processing approach as brought about by launching on an unmanned cargo vehicle. Mission control discussions emphasize variations resulting from the OTV's having different degrees of reusability. Launch and recovery implications address OTV concept differences in terms of performance and Earth return of reusable OTV elements. The system trade section compares the various OTV concepts and recommends a preferred concept. Cost data supporting the system trades is also presented. The final technical section is a system level description of the preferred concept.

1.4.2 Approach

The approach used to conduct the Phase II activity is shown in the logic flow of figure 1.4-1. A substantial portion of the required data base was provided by the Phase I analysis and also the STAS (Ref 7) study which had also analyzed comparable launch vehicles and mission models. Each of the OTV concepts were characterized for all technical aspects necessary to perform the mission model. The best ground based and space based concepts were found and then compared to select the preferred OTV concept. The major emphasis of the analysis was against the Rev. 9, Scenario 2 Mission Model. Sensitivities within this model as well as assessment of Scenario 1 and 5 models was also performed.

1.4.3 Key Groundrules and Assumptions

The top level Phase II study groundrules which influenced the nature of the recommended program are as follows:

a. Trade decisions to be based primarily on discounted (10%) LCC and Rev. 9, Scenario 2 Mission Model having 442 flights in the 1995-2010 timeframe.

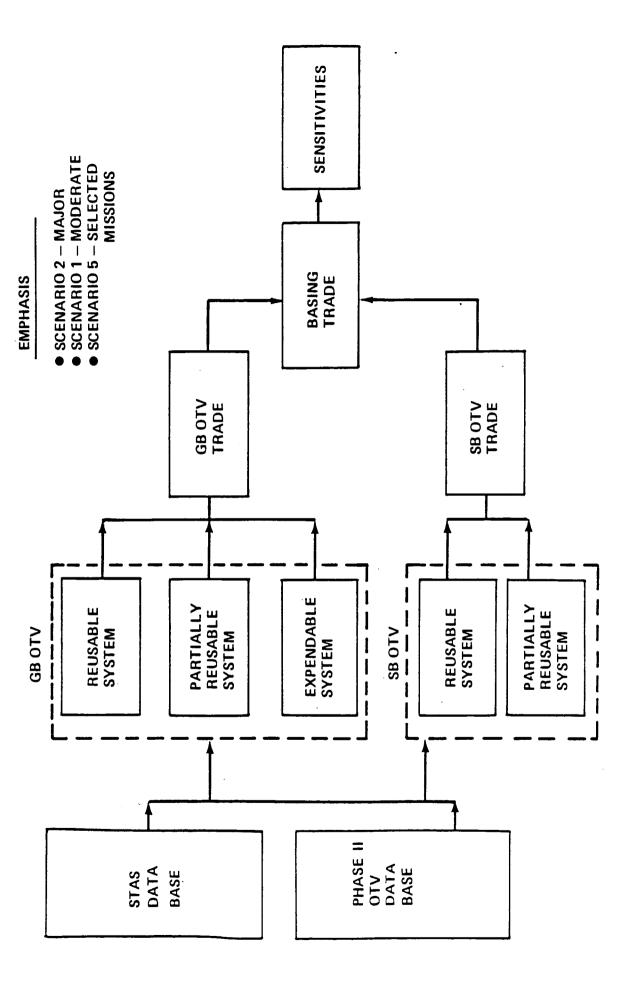


Figure 1.4-1 Phase II Activity

- b. An unmanned cargo launch vehicle (CLV) is available in 1995 with 150K lbm capability to 150 nm/28.5 degree at a cost per flight of \$70M. No DDT&E cost. The reference vehicle did not have cargo return capability. Further discussion follows.
- c. A new manned launch vehicle (STS II) with round trip payload capability is available in 2002 and can deliver 65K lbm to LEO at a cost of \$20M per flight. Further discussion follows.
- d. Launch cost assumes a users charge policy (i.e., STS).
- e. The IOC for GB OTV is 1995 and 1996 for a SB OTV.

The key assumptions are as follows:

- a. Main propulsion would be LO2/LH2 with advanced engine (selected in Phase I trade).
- b. A ballute would be used for the aeroassist device on reusable OTV's (selected in Phase I trade).
- c. Production learning cost factors of 90% for reusable elements (relatively low rates) and 85% for expendable elements (high rates).

Typical of the advanced launch systems to be considered were those defined by Boeing in the Ref. 7 study. The key characteristics of these vehicles are shown in figure 1.4-2. The majority of the cargo to be launched was done using a new unmanned cargo launch vehicle (CLV). This system employs a reusable booster and partially reusable second stage with 150klbm delivery capability and 25 ft. x 90 ft. payload fairing. No return capability is included. Payloads such as OTV related elements that must be returned used the current STS until 2002. At that point, a new fully reusable STS II was introduced. The cost related groundrules for these vehicles were no DDT&E impact and a cost per flight of \$70M and \$20M respectively for the CLV and STS II

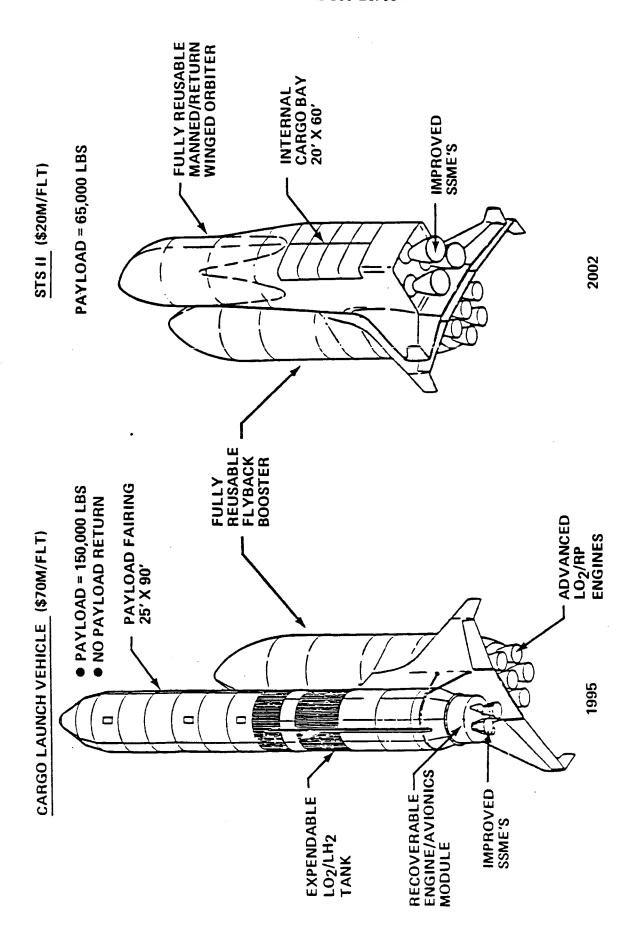


Figure 1.4-2 Advanced Launch Systems

2.0 MISSION ANALYSIS

The new Rev. 9 Mission Model had several important effects on the OTV mission analysis. These effects include changes in traffic level, orbital destinations, and vehicle sizing requirements. The Rev. 9 model was designed to reflect upper stage requirements identified in the Space Transportation Architecture Study (STAS) in order to ensure consistency between the two studies. The model reflects Civil and DOD requirements for varying levels of activity, as shown in figure 2.0-1. Study emphasis was on the nominal Scenario 2, though sensitivities were conducted with respect to Scenario 5, which has the highest level of OTV activity and involves aggressive expansion of Man's presence in space. Launch mass requirements for the five Rev. 9 scenarios are given in figure 2.0-2.

2.1 REV. 9 - REV. 8 COMPARISON

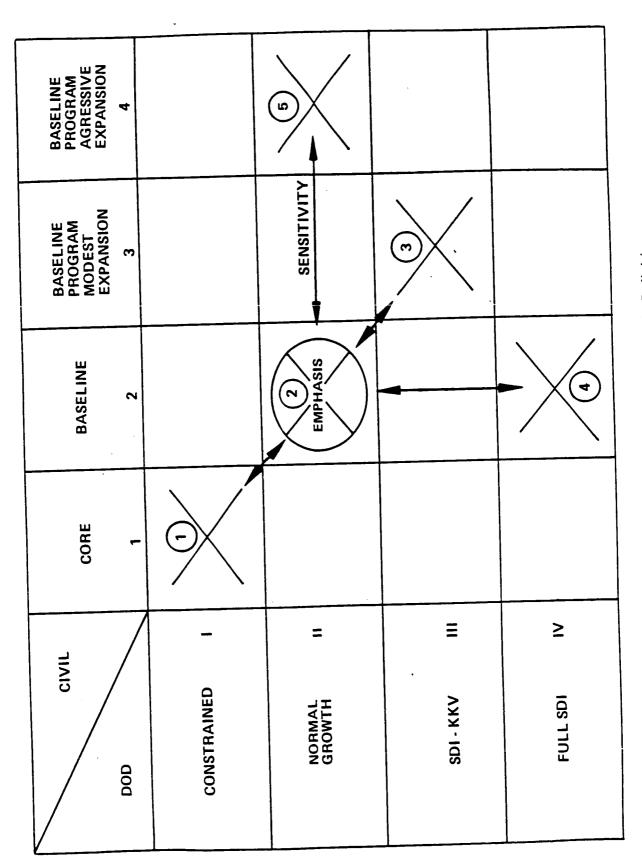
This section discusses the difference between the Rev. 9 Scenario 2 Nominal Model and the Rev. 8 Low Model. Summaries of these two models are given in table 2.1-1 and 2.1-2. The key differences between the two models is the level of activity: 365 flights in the Rev. 9 model compared with 160 flights in the Rev. 8 model as shown in figure 2.1-1. However the composition of the model is also different. The Rev. 9 model includes new DOD mission categories, retrieval missions, and significantly heavier GEO servicing and planetary missions.

The new DOD missions include high inclination (63.4 degrees, synchronous) and polar (4000 nmi) orbits in addition to the GEO missions included in the Rev. 8 model. In addition to these changes, the Rev. 9 DOD missions represent a larger proportion of the total model than for Rev. 8 (58% versus 34%). Though high inclination DOD missions were not specifically called out in the Rev. 8 model, it was assumed that 40% of the DOD payloads (expressed in GEO-equivalent terms) were associated with a Molniya-type orbit (i.e., DRM-2, which is described in Volume II, Book 1, Section 2.4-2). Therefore, the Rev. 8 analysis did incorporate the effects of high inclination missions, which have important effects on OTV performance (especially space-based concepts). The Rev. 9 high inclination missions were not to Molniya orbit so new DRM's had to be developed for the Rev. 9 analysis. These are described below in 2.3.

Two mission model changes affecting OTV sizing involve GEO servicing and planetary missions. Servicing changes are as follows:

1. Manned sortie mass increased to 10,000 lbs roundtrip from 7,500 lbs roundtrip.





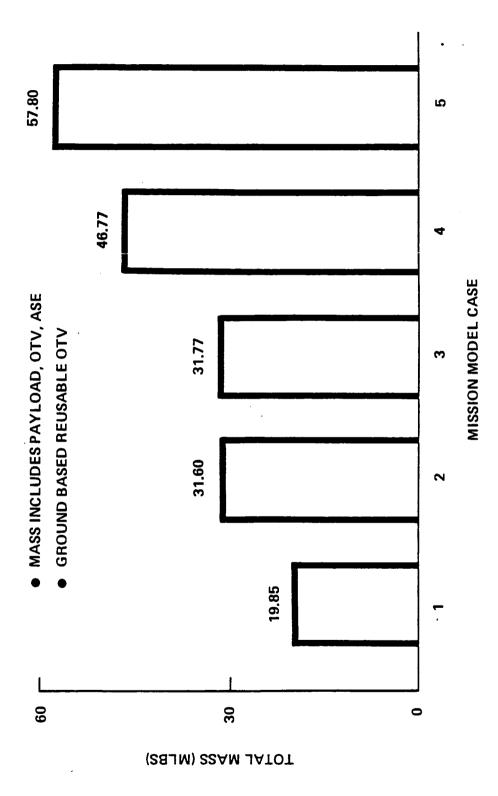


Figure 2.0-2. Mission Model Mass Comparison

Table 2.1-1. OTV Rev. 9 Mission Model Composition Summary

					·· · · ·												
	5	1	7	22	51	25	4	-	,-	ω	88	19	2	240 (96) (129)	391	17	872
UENCY	4	-	2	16	37	14	ო	ഥ	0	•	8	7	7	480	0	13	899
IO FREC	3	1	7	16	37	17	က	2	0	0	84	7	2	240	0	8	426
SCENARIO FREQUENCY	2	1	2	16	37	14	ო	ß	0	0	84	11	7	240 (96) (129)	0	8	423
	1	1	0	0	0	14	0	0	0	0	84	11	2	176	0	ល	293
WEIGHT (LB)	UPTDOWN	14550/0	16720-2508/0	12000/10000	12000/10000	1000-44100	5072/0	32850/0	93000/0	72680/20000	12000/2000	7055 - 21826	0/10030		10000/0		
di Coo incissiva	POOR BUOKSINI	EXPERIMENTAL GEO PLATFORM	GEO SHACK ELEMENTS	MANNED GEO SORTIE	GEO SHACK LOGISTICS	UNMANNED PLANETARY	UNMANNED LUNAR ORBIT	UNMANNED LUNAR SURFACE (PLD. TO LUN. ORB.)	LUNAR ORBIT STATION	MANNED LUNAR SORTIES/LOGISTICS (L.O. PLD.)	MULTIPLE GEO PAYLOAD DELIVERY	LARGE GEO SATELLITE DELIVERY	GEO SATELLITE RETRIEVAL	DOD (GEO) (MID-INCLINATION)	NUCLEAR WASTE DISPOSAL)0.88 A.U.)	REFLIGHTS	TOTAL
PAYLOAD	SERIES	13000	15000	15000	15000	17000	17000	17000	17000	17000	18000	18000	18000	19000	17300	10100	

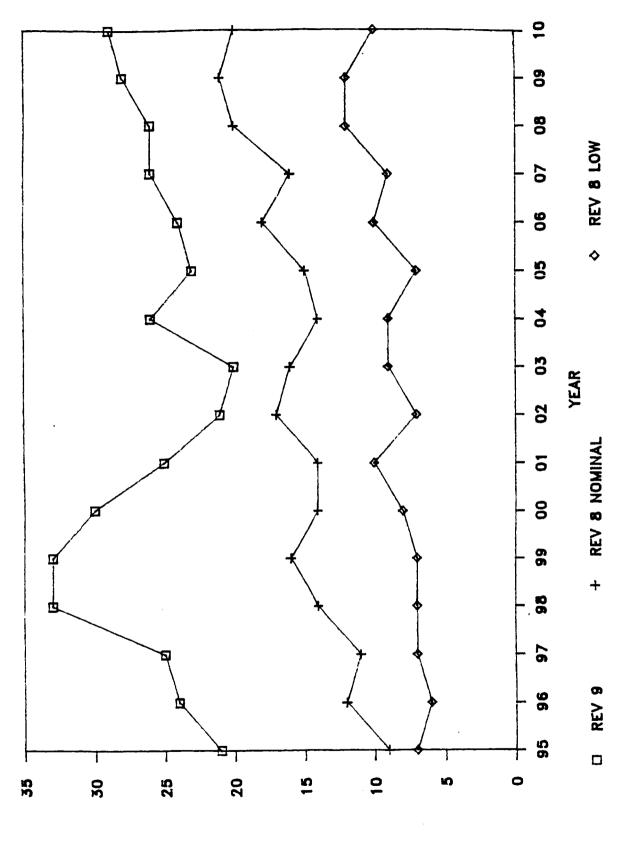
OTV-1035

Table 2.1-2. OTV Mission Model Composition Summary

1994 - 2010, REV. 8, 3-31-85

						_			 			_					-		 	7
	100		2000/1995	2004/1998	2001/1996	2008/2002	2002/1998	2004/1998	 1994/1994	2007/2001	2015/2006	2020/2008	2021/2009	1994/1994	2001/1997	1999/1994			1996/1997	
MODEL	WON	·	-	9	-	71	7	26	7.	'n	•	•	•	79	7	88		252	us .	257
MISSION MODEL	LOW		-	S	-	ю	2	ន	9	7	0	0	0	46	8	89		142	e	145
LENGTH	(FT)		30	36	3	10	15 – 20	16	2-36	20	20	53	09	25	20–35			SUBTOTALS		TOTALS
WEIGHT (LB)	UP/DOWN		12000/0	20000/0	7000/4500	7500/7500	13000/0	12000/2000	2000-40000/0	5000-20000/0	80,000/15,000	80,000/0	80,000/10,000	12000/2000	20000/0	12000-20000 (EQUIV.)				
	MISSION GROUP		EXPERIMENTAL GEO PLATFORM	OPERATIONAL GEO PLATFORM	UNMANNED GEO PLAT. SERVICING	MANNED GEO SORTIE	GEO SERVICE STATION ELEMENTS	GEO SERVICE STA. LOGISTICS	PLANETARY	UNMANNED LUNAR	MANNED LUNAR SORTIE	LUNAR BASE ELEMENTS	LUNAR BASE SORTIE/LOGISTICS	MULTIPLE GEO PAYLOAD DELIVERY	LARGE GEO SATELLITE DELIVERY	DOD (GENERIC)			REFLIGHTS	
PAYLOAD	SERIES		13000	13000	13000	15000	15000	15000	17000	17000	17000	17000	17000	18000	18000	19000			10100	





STHOLLY

- 2. Largest GEO Shack element increased to 24,080 lbs from 13,000 lbs.
- 3. Rev. 9 servicing generally begins earlier (1999 vs. 2004 for Rev. 8 Low model or 1998 for Rev. 8 Nominal model) and has higher annual logistics requirements (25,500 lbs/yr vs. 7,100 lbs/yr for Rev. 8 Low and 20,000 lbs/yr for Rev. 8 Nominal)

The key effect of the new model is that the manned sortic requires considerably more propellant than early delivery missions and thus two different sizes of vehicles are benefical. The model includes some very large planetary missions (specifically Pluto Orbiter and Neptune Flyby/Probe) which represent the largest OTV performance requirements. However, in keeping with earlier analysis groundrules that planetary missions would not be sizing missions, but would be launched in multistage OTV configurations, these large payloads did not impact Rev. 9 OTV's sizing. The Rev. 9 OTV planetary mission characteristics are shown in figure 2.1-2.

The Rev. 9 model also includes two retrieval missions. The payloads involved are 30 feet long and weigh 10,030 lbs. Though insignificant from a traffic level standpoint, these retrieval missions would have a major impact on aerobrake sizing, if an aerobraking approach were used for OTV recovery. It was therefore decided to conduct retrieval missions all-propulsively, which would avoid OTV design impacts.

2.2 SIZING MISSIONS

Figures 2.2-1 and 2.2-2 shows the OTV sizing missions for Rev. 9, Scenario 2 and Scenario 5, respectively. Scenario 2 is the reference nominal model and Scenario 5 is the model with the highest OTV traffic. The principal difference between the two is the lunar mission IOC, which determines when the large OTV must be developed. Table 2.2-1 gives the OTV sizing implementation for Scenario 2. The sizing missions for Rev. 8 are shown in figure 2.2-3 for comparison reasons.

2.3 DESIGN REFERENCE MISSIONS

Mission profiles for the Scenario 2 DRM's are given in figures 2.3-1 through 2.3-7. These mission profiles are delta-v requirements and timelines for both ground-based and space-based reusable and expendable OTV concepts. Note the different orbit transfer characteristics for the ground-based and space-based polar missions (figures 2.3-6 and 2.3-7). The difference is a result of the large plane change requirement for the SBOTV.



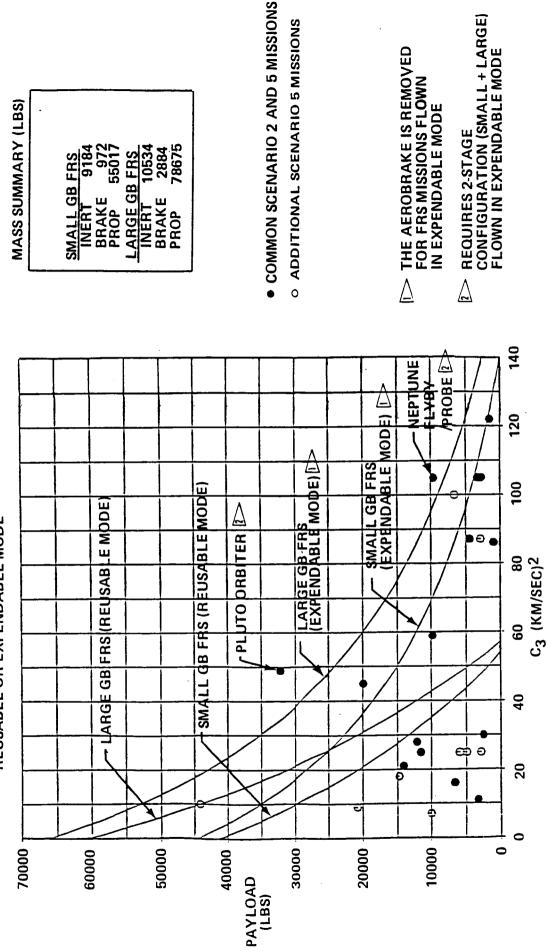


Figure 2.1-2. Planetary Mission Capture

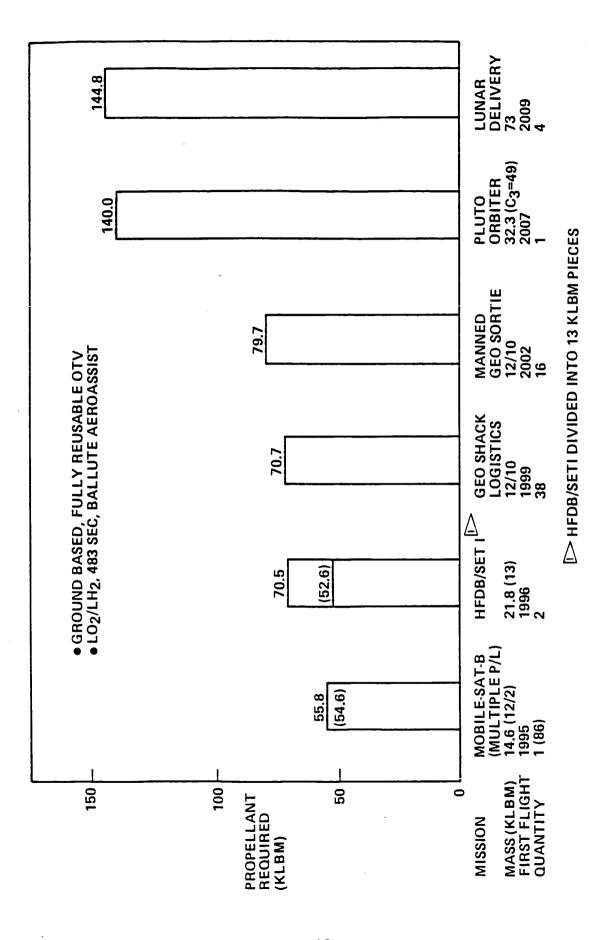


Figure 2.2-1. Scenario 2 OTV Sizing Missions

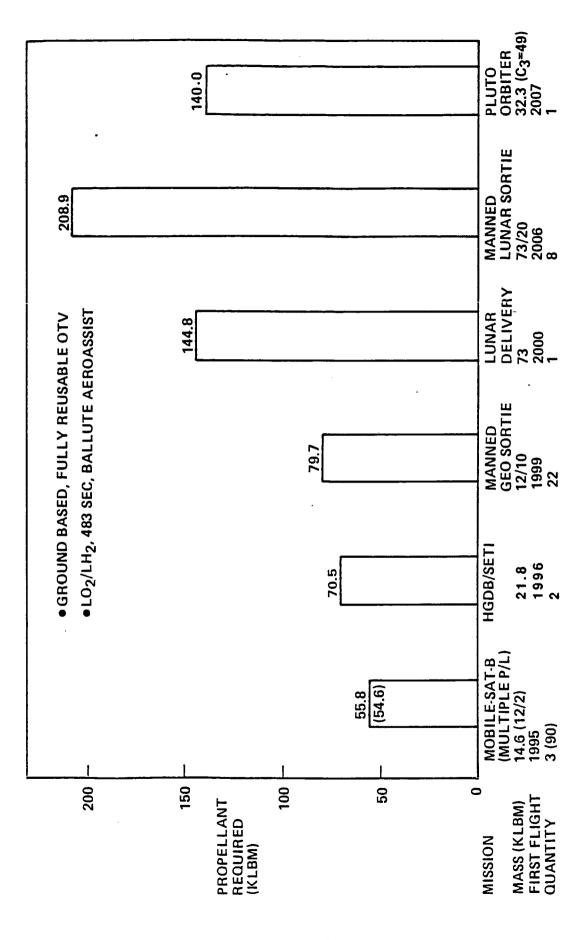


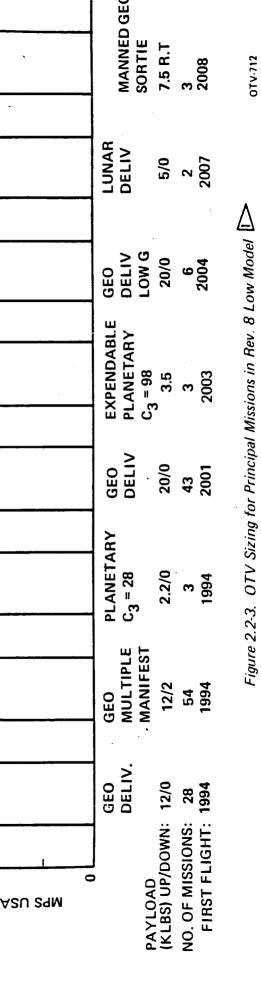
Figure 2.2-2. Scenario 5 OTV Sizing Missions

Table 2.2-1 Rev 9 OTV Sizing Implementation

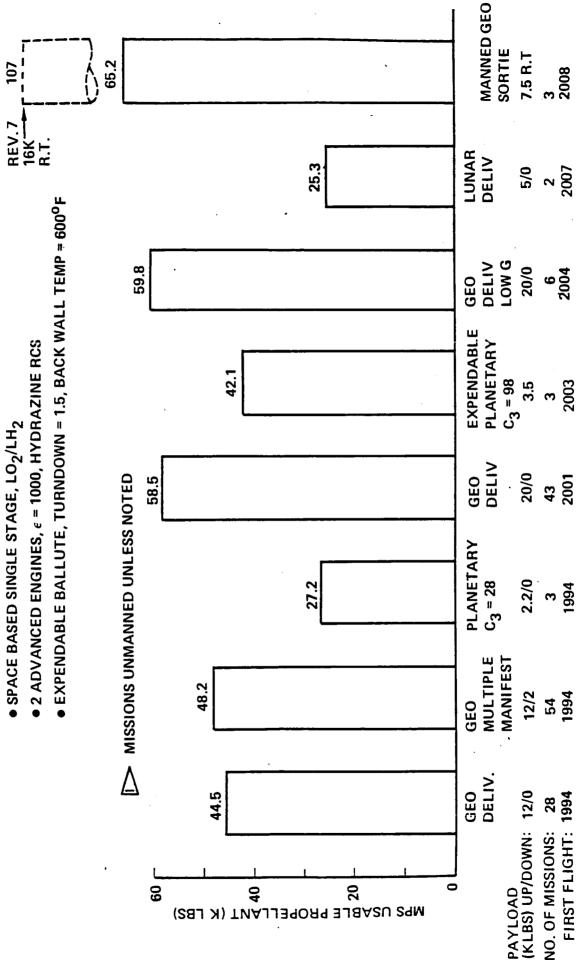
- DEVELOP SMALL, UNMANNED STAGE SIZED BY 14.6K GEO PAYLOAD (Wp = 55,800) FOR 1995 IOC.
- DEVELOP LARGE, MAN-RATED STAGE SIZED BY MANNED GEO SERVICING MISSION (Wp = 79,700 lbm) FOR 1999 IOC (GEO SHACK LOGISTICS MISSION).
- USE STAGE COMBINATIONS FOR LARGE, INFREQUENT MISSIONS.

PLANNED STAGE USAGE:

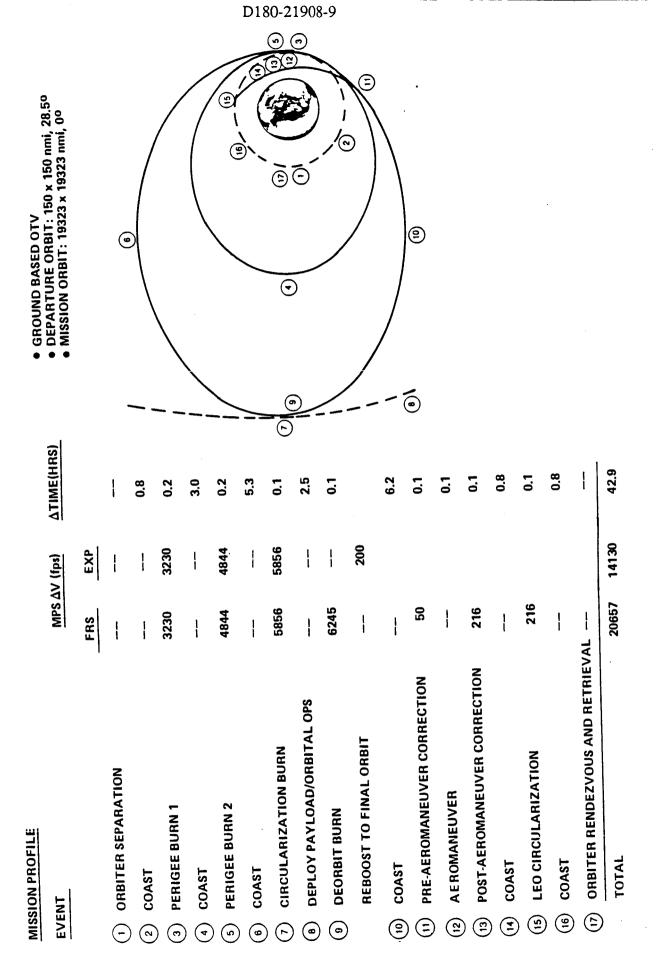
MISSION	PAYLOAD (LBM)	PROP. (LBM)	STAGE CONFIG.
 MULTIPLE GEO DELIVERY 	12,000/2,000	54,600	OFF-LOAD SMALL
• MOBILE-SAT-B	14,550	55,800	SIZING FOR SMALL
• HFVOADB/SETI	21,826	70,500	TWO STAGE SMALL
LOGISTICS/MANNED SORTIE	12,000/10,000	70,700	OFF. LOAD LARGE
 MANNED GEO SERVICING 	10,000/10,000	79,700	SIZING FOR LARGE
 PLUTO ORBITER 	32,305	140,000	TWO STAGE LARGE
LUNAR DELIVERY	73,000	144,800	TWO STAGE LABGE
• GEO SHACK - UTILITY	16,720	61,400	TWO STAGE SMALL
-HABITAT	25,080	75,400	OFF. LOAD LARGE







18



			PAXIOAD	ESCAPE	∆ , , , , , , , , , , , , , , , , , , ,			(E)			3	M10	(E)	(€	Ð					
ımi, 28.5º		el			-		~1	_	_	(೨	/								7.4
GROUND BASED OTV $C_3 = 30$ DEPARTURE ORBIT: 150 x 150 nmi, 28.50	∆TIME(HRS)	IN EXPEND	ļ	0.8	0.2	6.1	0.2	0.1				~	_	_		~	_	•		
ED OTV ORBIT: 1	ATIN	RETURN		0.8	0.2	6.1	0.2	0.1	0.1	30.3	0.1	30.3	0.1	0.1	0.1	0.8	0.1	0.8	i	2 70.2
GROUND BASED OTV C ₃ = 30 DEPARTURE ORBIT:	(fps)	EXPEND		}	6535	}	7987	1							•					14522
• GROU • C ₃ = 3 • DEPA	MPS AV (fps)	RETURN EXPEND		ļ	6535	1	7987	-	4744	1	8	1	20	}	216	1	216	1	·	19768
	MISSION PROFILE	EVENT	(1) ORBITER SEPARATION		3 PERIGEE BURN 1	(4) COAST	(5) PERIGEE BURN 2	(6) DEPLOY PAYLOAD	(au) RETRO BURN (RETURN MODE ONLY)	B COAST	9 DEORBIT BURN	(10) COAST	(1) PRE-AEROMANEUVER CORRECTION	(2) AEROMANEUVER	(3) POST-AEROMANEUVER CORRECTION	(COAST	(6) LEO CIRCULARIZATION	(6) COAST	(1) ORBITER RENDEZVOUS AND RETRIEVAL	

[> EXPENDABLE MODE ALSO PLACES OTV IN ESCAPE TRAJECTORY

Figure 2.3-3 Manned GEO Sortie Mission Profile (DRM-4)

		9								M-10 /	(I)								
	†	0.8	0.2	3.0	0.2	5.3	0.1	176.4	1.0	. 6				8.0	0.1		3.0	-	196.5
EXP	-	1	3230	1	4844	1	5856	504	6245		50	3	216		216	·		250	21411
FRS	1	***	3230	ļ	4844	1	5856	504	6245	ļ	20	1	216	1	216	!	1		21161
	(1) ORBITER SEPARATION	© COAST	(3) PERIGEE BURN 1	• COAST	(5) PERIGEE BURN 2	6 COAST	(1) CIRCULARIZATION BURN	ORBITAL OPERATIONS	(E) DEORBIT BURN	(10) COAST	(1) PRE-AEROMANEUVER CORRECTION	(2) AEROMANEUVER	(13) POST-AEROMANEUVER CORRECTION	(4) COAST	(6) LEO CIRCULARIZATION	(6) COAST	(1) ORBITER RENDEZVOUS AND RETRIEVAL	OTV DEORBIT	TOTAL

GROUND BASED OTV
DEPARTURE ORBIT: 150 x 150 nmi, 28.50
MISSION ORBIT: 19323 x 19323 nmi, 00

MISSION PROFILE

EVENT

ΔTIME(HRS)

MPS ΔV (fps)

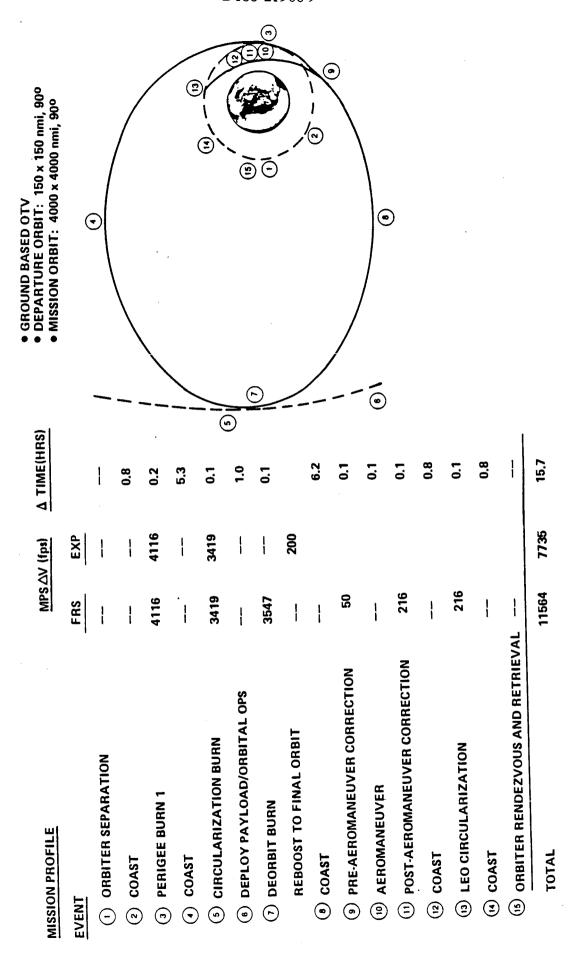
GROUND BASED OTV (SINGLE STAGE CONFIGURATION)
 DEPARTURE ORBIT: 150 x 150 nmi, 28.50

				•			(19)							120		•							
A TIME(HRS)		1	0.8	0.2	3.0	0.2	0.09	0.1		_	169.0	0.1	0.09	0.1	0.09	0.1	0.1	0.1	8.0	0.1	3.0		417.8
/ (fps)	EXP	1	ļ	4658	1	5692		160	1	2536	1	100				•							13146
MPS AV (fps)	FRS	1	ļ	4658	!	2693	1	160	1	2536	1	2536	1	160	!	20		216		216	1	1	16224
MISSION PROFILE EVENT		(1) ORBITER SEPARATION	(2) COAST	PERIGEE BURN 1	(4) COAST	EE BURN 2	(6) COAST	(7) MIDCOURSE CORRECTION	(B) COAST	(9) LUNAR ORBIT CIRCULARIZATION	(10) DEPLOY PAYLOAD/ORBITAL OPS	(1) DEORBIT BURN	(12) COAST	(13) MIDCOURSE CORRECTION	(1) COAST	(15) PRE-AEROMANEUVER CORRECTION	(16) AEROMANEUVER	(17) POST-AEROMANEUVER CORRECTION	(IB) COAST	(19) LEO CIRCULARIZATION	(20) COAST	(2) ORBITER RENDEZVOUS AND RETRIEVAL	TOTAL

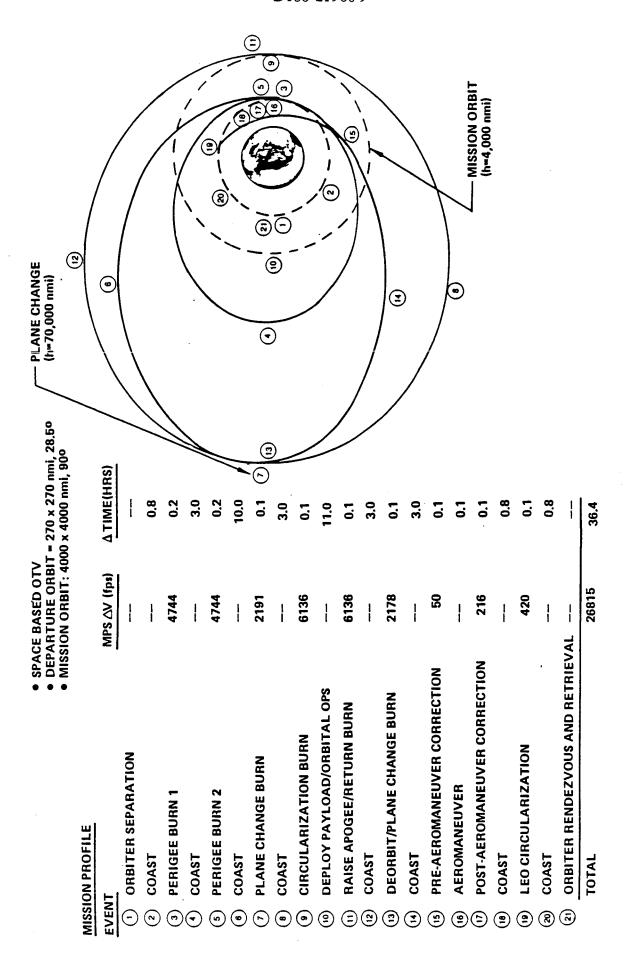
Figure 2.3-4 Lunar Delivery Mission Profile (DRM-5)

MISSION ORBIT: 19323 x 19323 nmi, 63.4°
 GROUND BASED DEPARTURE ORBIT: 150 x 150 nmi, 57°
 SPACE BASED DEPARTURE ORBIT: 270 x 270 nmi, 28 5°

MISSION PROFILE		•	SPACE BA	NSED DEPARTUR	 SPACE BASED DEPARTURE ORBIT: 270 x 270 nmi, 28,50
		MPS A	MPS AV (fps)	A TIME(HRS)	
	EXP	85	SB		
SEPARATION	ļ	i	1		•
		1	1	9.0	
PERIGEE BURN 1	3198	3198	3888	0.2	
		ŀ	!	3.0	
PERIGEE BURN 2	4796	4796	3888	0.2	
	-	1	; 	5.3	
CIRCULARIZATION BURN	4887	4887	6472	0.1	
DEPLOY PAYLOAD/ORBITAL OPS	l,			24.0	
DEORBIT BURN	İ	4946	6538	0.1	
REBOOST TO FINAL ORBIT	200		1		
-		ļ	1	6.2	
PRE-AEROMANEUVER CORRECTION		20	20	0.1	(a)
AEROMANEUVER				0.1	
POST-AEROMANEUVER CORRECTION		216	216	0.1	
		1	!	0.8	
LEO CIRCULARIZATION		216	420	0.1	
			!	0.8	
RENDEZVOUS AND RETRIEVAL		1	ļ	ŀ	
	13081 18309		21472	41.9	







100 11000 0

In order to minimize delta-v, the OTV is injected into a transfer orbit with a very high apogee where orbital velocity is low and where plane change delta-v would also be low.

3.0 OTV CONCEPTS

3.1 INTRODUCTION

The focus of the work in the second half of Phase 2 of the OTV study was the impact of using a cargo launch vehicle in conjunction with the Shuttle to launch payloads to LEO. This has significant impact on possible OTV configurations, and even opens up the field further to other possible configurations than those studied up through the first half of phase 2. With a cargo launch vehicle having lower launch costs, OTV's with a lesser degree of reusability can be viable options. Thus, for this period of the study, partially reusable vehicles were studied for both ground-basing and space-basing as were expendable vehicles. In addition, fully reusable ground and space based vehicles, were investigated. The key features of the six OTV concepts are indicated in table 3.1-1. Figure 3.1-1 shows the top-level configuration characteristics of the GB The partially reusable system (PRS) includes a reusable OTV's studied. propulsion/avionics (P/A) module and an expendable tank module. The logic behind this design is that the more expensive engines and avionics components are recoverable, while the less expensive tanks and structure can be thrown away. The P/A module has a lifting brake device in order to perform an aeromaneuver and be recovered at LEO. The P/A module is then returned in the Orbiter cargo bay. The lifting brake is expendable, as it is too large to be returned in the Orbiter cargo bay.

The fully reusable system (FRS) includes a fully reusable stage and an expendable ballute aerobrake. In this system, the stage performs the mission, does an aeromanuever, jettisons the ballute, and then is returned in the Shuttle cargo bay to earth. This constrains the diameter of the vehicle to under fifteen feet in order to fit into the Shuttle bay.

The expendable OTV system includes a stage that is completely expendable. The advantage in this strategy is that the stage can be significantly smaller and lighter than a reusable system because it only needs to go one way for payload delivery missions. Because it is launched in a cargo launch vehicle and not returned to earth, the diameter of the vehicle is not constrained by the Shuttle bay diameter.

3.2 LAUNCH VEHICLES AND BASELINE SUBSYSTEMS

For this part of the study a cargo launch vehicle having a payload capability of 150,000 lb to 150 nm with a payload bay of 28 foot diameter and 90 feet long was assumed. This payload envelope is enclosed in a payload shroud which is jettisoned during flight. The Shuttle was assumed to be the OTV return vehicle having a payload

Table 3.1-1. Candidate OTV Concepts

CONCEPTS

REUSABLE SYSTEM (GB FRS) **GROUND BASED FULLY**

- REUSABLE SYSTEM (GB PRS) GROUND BASED PARTIALLY
- NEW EXPENDABLE (EXP)
- **NEW EXPENDABLE WITH AERO-ASSIST PAYLOAD RETURN**
- REUSABLE SYSTEM (SB FRS) SPACE BASED FULLY
- REUSABLE SYSTEM (SB PRS) SPACE BASED PARTIALLY

KEY FEATURES

- **AEROASSIST ORBIT RETURN**
- REUSABLE EXCEPT FOR BRAKE
- **MAJOR EARTH RETURN NEEDS**
- RETAINS PROPULSION AND AVIONICS **AEROASSIST ORBIT RETURN**
 - REDUCED EARTH RETURN NEED
- **ALL PROPULSIVE ORBIT RETURN**
 - ▶ LEAST WEIGHT FOR DELIVERY NO EARTH RETURN NEEDS
- LOWER ROUNDTRIP LAUNCH WEIGHT THAN EXPENDABLE
- **LOWER LAUNCH WEIGHT AND REDUCED** EARTH RETURN NEEDS (REL. TO GB FRS)
 - **EXTENSIVE ORBITAL SUPPORT**
- **ELIMINATES PROPELLANT LOGISTICS** SYSTEM AND EARTH RETURN NEEDS OF SB FRS

REV. A

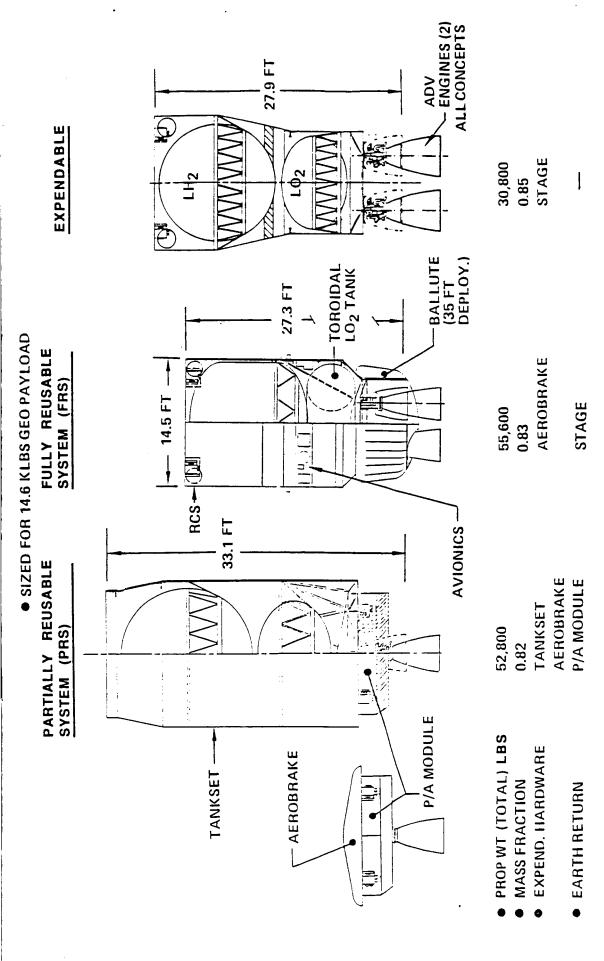


Figure 3.1-1 GB OTV Concepts, Delivery Mission Configuration

bay of 15 foot diameter by 60 feet long. All return payloads or OTV's must be returned in the Shuttle since the cargo launch vehicle is expendable and cannot return payloads to earth. The comparative sizes of these payload bays are shown in figure 3.2-1.

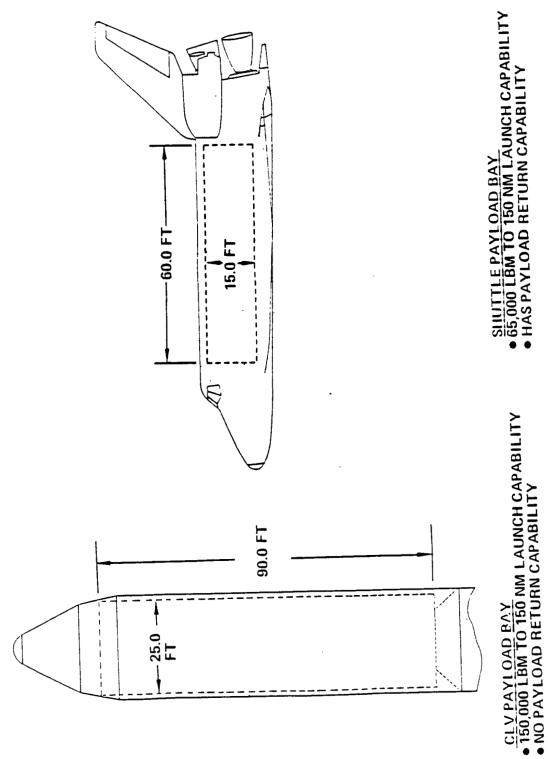
Subsystem features common to most of the Orbital Transfer Vehicles are given to Table 3.2-1. Variations from these features do occur, according to the particular design or reusability of the vehicle. In the structures area, maximum use is made of advanced composites such as GR/EP and GR/PI for body structures. In all vehicles, the propellant tanks are of 2219-T87 aluminum. For meteoroid/debris shielding, the ground-based vehicles are shielded by the GR/EP outer body shell, whereas the space-based vehicles need an extra aluminum bumper shield protecting the tankage areas. The main engines are sized for each type of vehicle according to the performance for the sizing mission in the mission model, most commonly the manned servicing mission, using an initial thrust-to-weight ratio of 0.12.

The structural design criteria used for the design of the vehicles considered in this phase of the study are similar to those used in the past. For expendable vehicles, however, the tankage is designed for a service life of only one mission instead of forty-five. This results in a decrease of tank weight. A summary of the design criteria used in this period of the study is given in Table 3.2-2.

3.3 GB FULLY REUSABLE OTV

3.3.1 Mission Application

Figure 3.3-1 shows the vehicle evolutionary path of the ground-based fully reusable vehicle as applied to the mission model. Several options are possible for this evolutionary path. The vehicle could be sized to do all missions in the model and would be offloaded for the early missions. This option would penalize the small delivery missions, which are the majority of the missions in the model. Another option is to size the stage to do the early delivery missions, use a two stage vehicles for all larger missions, and man-rate the vehicle when the manned missions are performed. This option would penalize the return payload (roundtrip) missions because of additional inert weight and would not allow the return payloads to be returned in the Shuttle bay with the two stages because of length. The preferred option, shown in Figure 3.3-1, incorporates initial vehicles sized to perform the small delivery missions and uses these relatively small stages in a two-stage configuration for the larger missions until the manned mission era. These small stages are sized for a usable propellant loading of 55,000 lb. In the manned mission era, a new large stage is sized that is man-rated and



SHUTTLE PAYLOAD BAY

• 65,000 LBM TO 150 NM LAUNCH CAPABILITY

• HAS PAYLOAD RETURN CAPABILITY

Figure 3.2-1 Payload Bay Configurations Cargo Launch Vehicle and Shuttle

Table 3.2-1 Common Subsystem Features

SUBSYSTEM

STRUCTURES

- BODY
- TANKAGE
- DEBRIS/METEROID PROTECTION
- MAIN PROPULSION
- RCS PROPULSION
- ELECTRICAL POWER
- THERMAL CONTROL
- AVIONICS
- GUIDANCE AND NAVIGATION
- T, T&C
- DATA MANAGEMENT
- INSTRUMENTATION

BASELINE FEATURES

- ADVANCED COMPOSITES (GR/EP, GR/PI)
- 2219-T87 ALUM (MAX PRESS 18 · 22 PSIA)
- **16 MIL ALUM BUMPER WITH MLI**
- (2) ADVANCED ENGINES $P_c = 1500$, $\epsilon = 1000$, T/W = .12 FOR SIZING MISSION
- AUTOGENOUS PRESSURIZATION (16 - 24) 25 LBF THRUSTERS (100 LBF REQUIRED ON P/A MODULES)
- 2.0 kW NOM/3.5 kW PEAK O₂/H₂ FUEL CELLS

N₂H₄ WITH N₂ PRESSURIZATION — CONSTANT PRESSURE SYSTEM

- SUPERCRITICAL 02/H2 STORAGE
 NIH2 AUXILIARY BATTERIES
 - DAK MLI WITH DACRON SCRIM
- FOSR ON EPS RADIATOR AND SELECTED AVIONICS
- REDUNDANT IRU, STAR TRACKERS, GPS
- TDRS TRANSPONDERS, RF AMPS
- INTERNALLY REDUNDANT DMU'S
 - HIGH SPEED DATA BUS
- REDUNDANT ZERO G PROPULSION GAGES
- SUBSYSTEM MONITORING WITH SOFTWARE FOR ON-ORBIT CHECKOUT/TEST

Table 3.2-2 OTV Structural Design Criteria/Guidelines

PRIMARY STRUCTURE

• ULTIMATE LOAD= 1.5 X LIMIT LOAD

	REUSABLE	ABLE	EXPER	EXPENDABLE
TANKAGE	LH ₂	L0 ₂	LH ₂	L0 ₂
LEAK BEFORE RUPTURE	YES	YES	YES	YES
MINIMUM FACTOR OF SAFETY TO YIELD	1.5	1.5	1.5	1.5
DESIGN SERVICE LIFE (MISSIONS)	45	45	-	
● VENT TO REFILL	YES	PARTIAL		
• EQUIVALENT FULL DEPTH CYCLES	52	4	_	
• CONTINGENCY CYCLES	2	5	ស	5
 SCATTER FACTOR 	2	2	7	2
DESIGN CYCLES	120	18	12	12
 ROOM TEMP PROOF FACTOR 	1.63	1.33	1.25	1.25

METEOROID/DEBRIS SHIELDING

- PROVIDE .999 PROBABILITY OF NO TANK WALL IMPACT PER MISSION
- MINIMUM METALLIC SHEET IS ASSUMED TO BE .016 IN. FOR BUMPER
- SHIELDING DESIGN IS DRIVEN BY DEBRIS FLUX AT LEO (12 HOUR EXPOSURE)

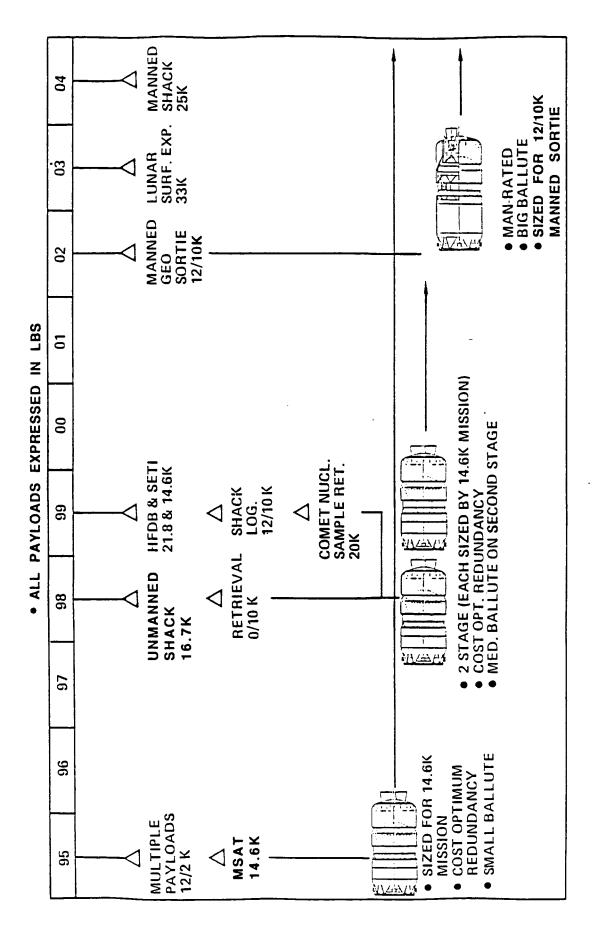


Figure 3.3-1 FRS OTV Mission Application

sized to perform the return payload missions. This stage has a usable propellant capacity of 78,700 lb.

3.3.2 Operational Description

Both the small and large vehicles are launched from the ground in an unmanned launch vehicle with the payload attached. In the case of delivery missions, the stage with payload separates from the launch vehicle at LEO, delivers its payload, deorbits and performs a ballute aeromaneuver, and then returns to LEO to await return to earth on board the Shuttle. In the case of a return payload, the mission is performed then the stage and payload are returned to LEO to await return in the Shuttle. When two stages are used, the first stage performs the first perigee burn and is separated to return to LEO. The second stage goes on to perform the remainder of the mission and return the payload via aeromaneuver.

When a manned mission occurs, the stage with empty crew module is launched to the Space Station, the crew is loaded, and the mission is performed. The crew is then returned to the Space Station and the stage and crew module are returned to earth. These operations are shown in figures 3.3-2 and 3.3-3.

3.3.3 Configuration Description

The configurations for the small and large stage ground-based OTV's are given in figures 3.3-4 and 3.3-5. Weight summaries for these stages are given in Tables 3.3-1 and 3.3-2. Spacecraft structure consists primarily of a graphite/epoxy honeycomb sandwich body shell enclosing strut-supported 2219-T87 aluminum propellant tanks. Meteoroid/debris protection is provided by the body shell and MLI insulation around the tanks. This system provides a 0.9995 probability of no tank wall impact for the mission. Main propulsion thrust is provided by two advanced expander cycle engines, each having a vacuum thrust of 6000 lbf. These engines provide thrust for all orbit transfer maneuvers. Auxiliary propulsion is provided by a hydrazine system pressurized by nitrogen gas supplied from separate gas bottles. Electrical power for the mission power usage is provided by O2/H2 fuel cells, operating from supercritical O2/H2 storage bottles. Active thermal control is provided for these fuel cells. Other thermal control includes MLI on the main propellant tanks for propellant boiloff control and flexible reusable surface insulation (FRSI) on the vehicle exterior for thermal protection during the aeromaneuver.

For the aeromaneuver, high backwall-temperature ballutes are used. For small payload delivery missions, a 34.4 ft diameter ballute is needed to perform the

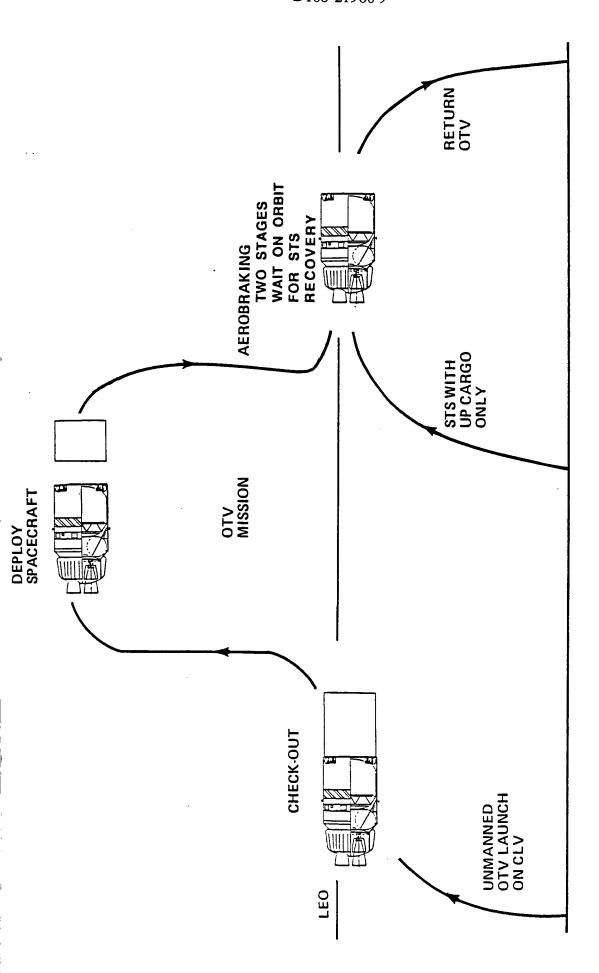


Figure 3.3-2 FRS Flight Operations Payload Delivery Mission—Ground Based

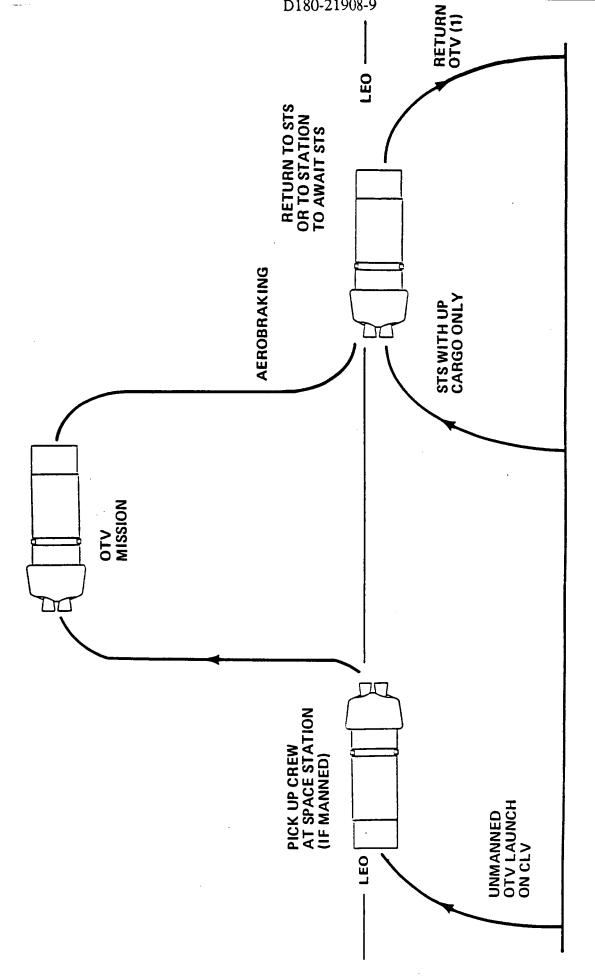
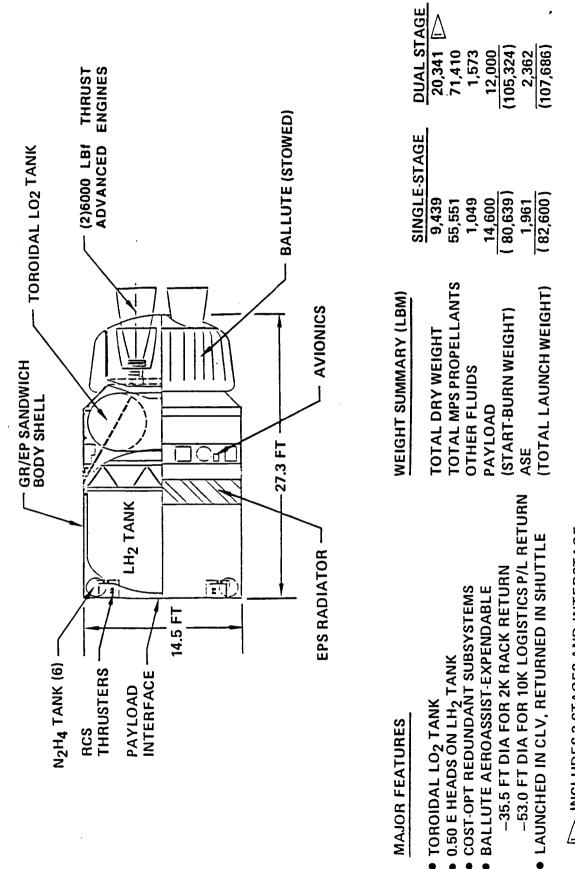


Figure 3.3-3 FRS Flight Operations Payload Return Mission—Ground Based



INCLUDES 2 STAGES AND INTERSTAGE

Figure 3.34 Small GB Fully Reusable OTV Configuration

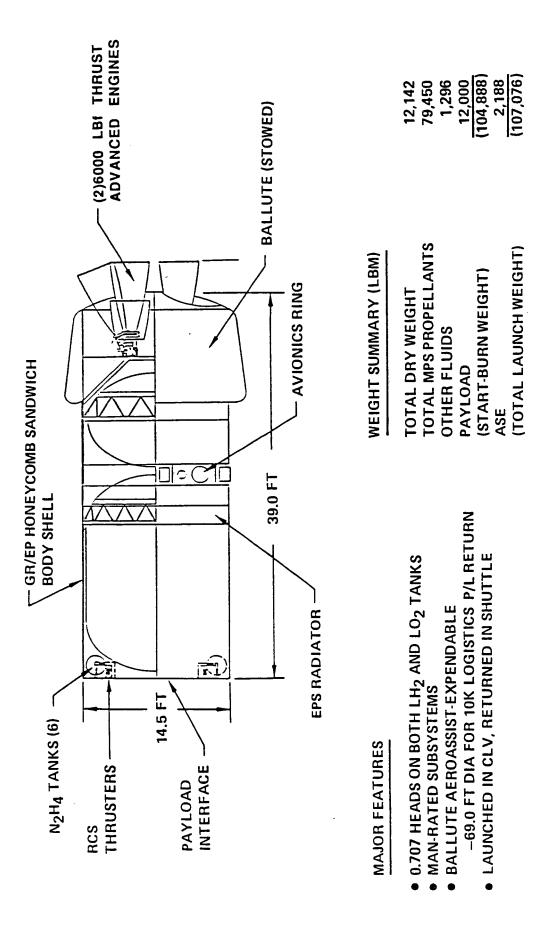


Figure 3.3-5 Large GB Fully Reusable OTV Configuration

WEIGHT (LBM)	53.0 FT. DIA. BALLITE
WEIGH	35.5 FT. DIA. BALLITE

Table 3.3-2 OTV Weight Summary Large GB Fully Reusable OTV, Man-Rated

3943	2407	1489	47	3216	2062	1154	758	646	428	262	135	468	751	1535	(12,142)	802	-2803	(10,141)	+2803	08	114	1050	78,700	(92,888)
STRUCTURES AND MECHANISMS	BODY STRUCTURE	TANKAGE	MET/DEB SHIELDING	AEROASSIST DEVICE	STRUCTURE	THERMAL PROTECTION	THERMAL PROTECTION AND CONTROL	MAIN PROPULSION, LESS ENGINES	MAIN ENGINES (2-6000 lbf ASE)		GUIDANCE AND NAVIGATION		ELECTRICAL POWER	WEIGHT GROWTH	(DRY WEIGHT)	RESIDUALS	JETTISONABLE ITEMS, INCLUDING GROWTH	(EOM WEIGHT, EXCLUDING RESERVES)	JETTISONABLE ITEMS, INCLUDING GROWTH	EPS REACTANTS	PRESSURANTS	RCS USABLE PROPELLANTS (INCLUDING FPR)	MPS USABLE PROPELLANTS (INCLUDING FPR)	(GROSS WEIGHT)

aeromaneuver. This diameter was selected to preclude wake impingement on the empty payload rack that is returned on some multi-manifest missions. For large return payload missions, particularly the 12k lb logistics payload return, a 53.0 ft diameter ballute is needed. These sizes are determined by aerostability criteria and are sufficient to protect the payload from wake impingement during the aeromaneuver.

With the small stage, length becomes a critical factor because the stage is returned to earth in the Shuttle. In order to return two of these small stages in the Shuttle bay, the stages were shortened by using a toroidal LO2 tank and flattening the heads of the LH2 tank to 0.5 ellipses. The performance of the vehicle was degraded by adding the extra weight associated with the tank changes, but it is possible to fit two empty stages in the Shuttle bay for return to earth. This minimizes the cost of extra Shuttle launches to return vehicles to earth. Figure 3.3-6 illustrates the benefits and weight penalty resulting from the changes. Another consideration of returning two stages in the Shuttle bay is the need for those stages to remain on-orbit for a period of time to await the Shuttle return. During this time the subsystems are partially shut down. In order to do this, extra subsystems must be added to the vehicle to maintain it during this period. Extra RCS propellant is needed for attitude control and a solar array re-chargeable battery system must be added to power the systems during this period. The body shell with MLI and FRSI provides in excess of 0.99 probability of no tank impact by meteoroids/debris during the dormancy period of 21 days (max time before two small stages available for return) and was considered sufficient during this non-critical portion of the mission. These on-orbit dormancy provisions, with weight scars, are shown in Table 3.3-3.

The large GB fully reusable stage is not constrained by return length and therefore makes use of 0.707 elliptical domes on both tanks and does not include dormancy provisions.

3.3.4 Launch and Return Concepts

Because the GB fully reusable vehicles are launched in the cargo launch vehicle and returned in the Shuttle, they must be designed to be compatible with both systems. Figures 3.3-7 and 3.3-8 show the launch and return concepts for the small and large stages. In the case of a dual stage launch, a forward-bearing reaction system is used to react a portion of the lateral launch loads into the payload shroud. For return in the Shuttle, the OTV's have trunnion and keel fittings and latches installed in the Shuttle. These fittings and latches are charged to the payload, as well as repressurization systems are included in the OTV return ASE weight as shown in Tables 3.3-4 and 3.3-5.

SIZED FOR 14.6 KLBS GEO PAYLOAD

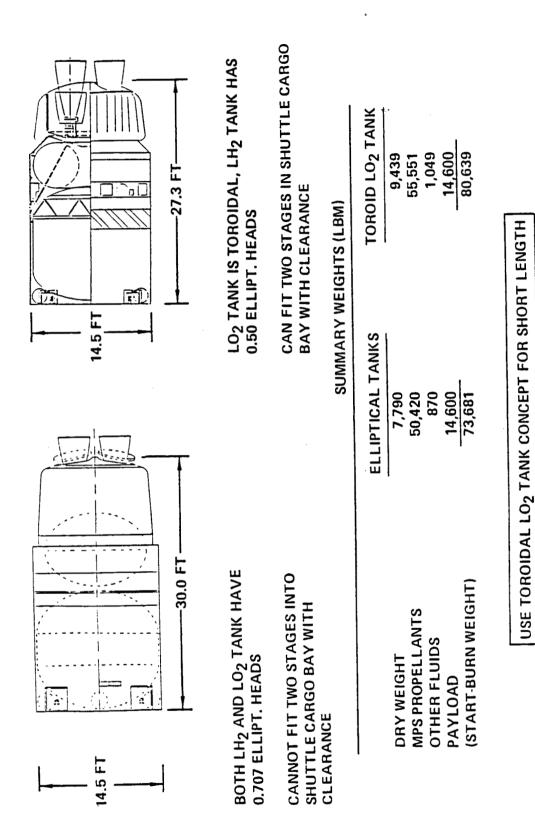
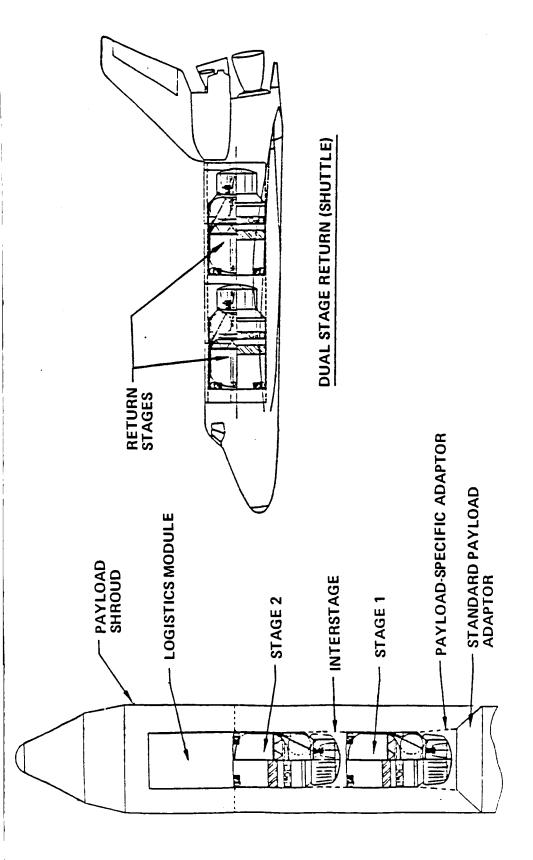


Figure 3.3-6 GB FRS Small Stage Configuration Trade

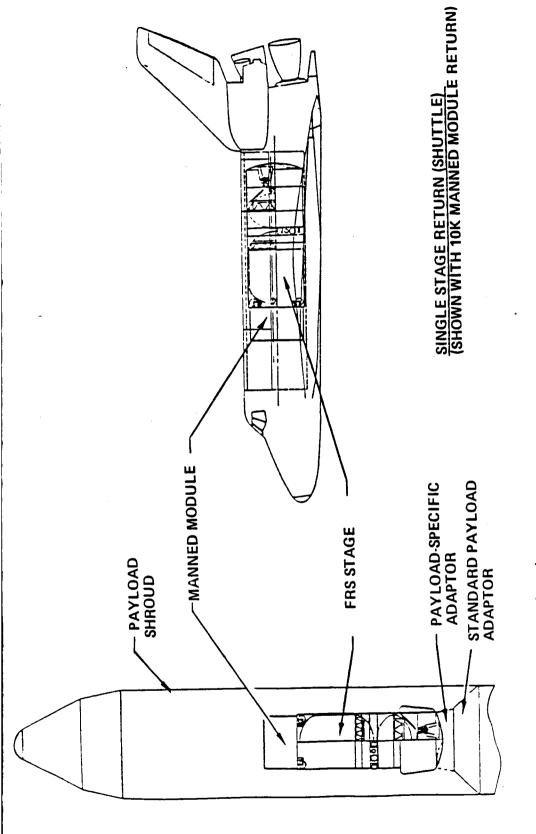
Provisions
Dormancy
On-Orbit
GB FRS On-
Table 3.3-3 (

WEIGHT (LBM)	120	26	329	1	∞	483
VEHICLE MUST STAY ON-ORBIT @ LEO FOR 21 DAYS TO AWAIT RETURN TO EARTH	 RCS IMPACT - PROPELLANTS FOR ATTITUDE CONTROL AND ORBITAL MANEUVERING/RENDEVOUS —EXTRA HYDRAZINE TANK AND 90 LB PROP 	 AVIONICS IMPACT - SUN SENSOR, HORIZON SENSORS, AND ASSOCIATED ELECTRONICS 	 ELECTRICAL POWER IMPACT - SOLAR ARRAYS TO CHARGE NICA BATTERIES FOR REDUCED POWER REQ'T 	 MET/DEB SHIELD IMPACT - EXISTING BODY GR/EP BODY SHELL, WITH FS! AND ML! PROVIDES IN EXCESS OF .990 PROBABILITY OF NO TANK IMPACT FOR NON- CRITICAL DORMANCY PERIOD 	 THERMAL CONTROL IMPACT - INSULATION FOR SOLAR ARRAY COVERS 	TOTAL WEIGHT



DUAL STAGE LAUNCH (CLV) (SHOWN WITH 12K LOGISTICS MODULE)

Figure 3.3-7 GB FRS - Small Stage Launch and Return Concepts



SINGLE STAGE LAUNCH (CLV) (SHOWN WITH 12K MANNED MODULE)

Figure 3.3-8 GB FRS-Large Stage Launch and Return Concepts

	CLV LAUNCH 1-STAGE	CLV LAUNCH 2-STAGE	SHUTTLE LAUNCH	SHUTTLE RETURN 2-STAGE
● COMMON GOV'T FURN. EQUIP.			323	
FITTING ALLOWANCE	ı	ı	-675	ı
• CABLING, MISC	ı	ı	866	ı
 PAYLOAD SUPPORT EQUIP 	100	100	100	ı
• ATTACH FTGS	ı	ì	ı	1
 PAYLOAD KITS 	100	100	100	ı
• CONTRACTOR EQUIP.	ı	ì	ı	
STAGE SUPPORT EQUIP.	1861	2362	8909	4187
ATTACH FTGS	ı	I	1705	2090
• MISC, GFE	ı	ı	370	370
• CONTRACTOR EQUIP.	1861	2362	3993	1727
(TOTAL)	1961	2462	6491	4187

WEIGHTS GIVEN ARE EQUIVALENT WEIGHTS TO ORBIT (SOME EQUIP IS JETTISONED WITH SHROUD)
 SHUTTLE LAUNCH OF SINGLE STAGE WITH PAYLOAD IS SHOWN FOR COMPARISON
 DUAL STAGE LAUNCH ASE INCLUDES FORWARD BEARING REACTION SYSTEM (FBRS) AND FILL/DRAIN PROVISIONS FOR SECOND STAGE

○ ASSUMED INCLUDED IN LAUNCH VEHICLE WEIGHT

(?> CHARGED TO UP PAYLOAD

	WEI	WEIGHT (LBM)
	CLV LAUNCH	SHUTTLE RETURN
COMMON GOV'T FURN EQUIP	Δ	
FITTING ALLOWANCE	ı	1
CABLING MISC	l	I
● PAYLOAD SUPPORT EQUIP	100	936
ATTACH FTGS.	ı	836
PAYLOAD KITS	100	100
● CONTRACTOR EQUIP	ı	l
 STAGE SUPPORT EQUIP 	2088	2816
 ATTACH FIGS. 	ı	1224
• MISC, GFE	1	370
 CONTRACTOR EQUIP. 	2088	1222
(TOTAL)	2188	3752

WEIGHTS ARE EQUIVALENT WEIGHTS TO ORBIT

○ INCLUDED IN LAUNCH VEHICLE WEIGHT

☼ CHARGED TO UP PAYLOAD

Also included in this table, for comparison purposes, is the ASE required to launch a GB OTV in the Shuttle. For the Shuttle launch, the ASE weight includes keel and trunnion bridge fittings, fill/drain/and dump systems, dump pressurization provisions, and vehicle support structure. The cargo launch vehicle ASE weight includes payload-specific adaptors, forward-bearing reaction system, and fill/drain provisions.

3.4 GB PARTIALLY REUSABLE OTV

Table 3.4-1 shows the differences between the GB fully reusable and partially reusable OTV subsystems. In both vehicles the tanks are launched full and the body structures are designed to take the associated launch loads. However, the tanks on the partially reusable vehicle are expendable and consequently are designed for a single mission service life resulting in lighter weight. In the partially reusable vehicle, all of the avionics, RCS, and main propulsion subsystems are situated in the propulsion/avionics module which is reusable. The RCS includes larger thrusters than those on the fully reusable vehicle in order to perform the post-aero delta V maneuver. Also, instead of a ballute aeroassist device, the partially reusable vehicle uses a symmetric lifting brake on the P/A module to perform an aeromanuever. This is due to the fact that integration of a ballute onto the P/A module would be difficult, given the P/A module dimensions.

3.4.1 Mission Application

Figure 3.4-1 shows the evolutionary path of the ground-based partially reusable vehicle as applied to the mission model. As before, several options are available for this vehicle evolution. The selected method, as shown in the figure, sizes the tankset for two types of missions; 14.6k-lb delivery missions and 12k/10k-lb roundtrip missions. The smaller vehicle is sized for a usable propellant loading of 52,300 lb while the larger vehicle is sized for a usable propellant loading of 93,000 lb. The P/A module is the same size for all vehicles and is man-rated prior to initiation of manned missions.

3.4.2 Operational Description

Both the small and the large partially reusable vehicles are launched from the ground in the unmanned cargo launch vehicle with the payload attached. For delivery missions, the stage and payload separate from the cargo launch vehicle, performs the delivery at the GEO, and the stage deorbits. The tankset is targeted for earth impact and then separates from the P/A module. The P/A module then performs an apogee boost, using RCS, to target the aeromaneuver. The separation is done so that the P/A

Table 3.4-1 GB FRS and PRS Subsystem Comparison

ITEM	GB FULLY REUSABLE OTV	GB PARTIALLY REUSABLE OTV
• BODY STRUCTURES	GR/EP BODY SHELL DESIGNED FOR LAUNCH LOADS	TANK MODULE—SAME
• TANKAGE	STRUT-SUPPORTED 2219-T87 ALUM., DESIGNED FOR 45 MISSION LIFE	TANK MODULE—SAME, BUT DESIGNED FOR 1 MISSION LIFE
• MET/DEB PROTECTION	PROVIDED BY GR/EP BODY SHELL/MLI 9995 PROB. OF NO. TANK IMPACT	TANK MODULE-SAME
• THERMAL PROTECTION & CONTROL	FSI ON BODY FOR HI-TEMP BALLUTE; MLI ON TANKAGE; FUEL CELL RAIDATORS	NO FSI ON BODY; MLI—SAME; FUEL CELL RADIATORS ON P/A MOD.
AUXILIARY PROPULSION	N ₂ H ₄ EXTERNAL PRESS. DIAPHRAGM TANKS, 25-LBf THRUSTERS	SAME, BUT WITH 4-100 LBf THRUSTERS FOR POST-AERO AV
• MAIN PROPULSION	2-6000 LBf ADVANCED ENGINES	2-7000 LBf ADVANCED EDNGINES, DIS- CONNECTS BETWEEN TANK MOD/PA MOD
• GUIDANCE & NAVIGATION	IMU, STAR TRACKER, GPS	SAME, LOCATED IN P/A MODULE
• COMMUNICATIONS/DATA	TDRS TRANSPONDER, INTEGRATED DMS, LOADING & HEALTH INSTRUMENTATION	SAME, IN P/A MODULE
• ELECTRICAL POWER	2.0 KW NOM O2/H2 FUEL CELLS; SOLAR ARRAYS FOR ON-ORBIT DORMANCY	SAME, IN P/A MODULE
• AEROASSIST	1500° B/W TEMP, EXPENDABLE BALLUTE	550° B/W TEMP. RIGID LIFTING BRAKE WITH ABLATOR TPS ON P/A MODULE



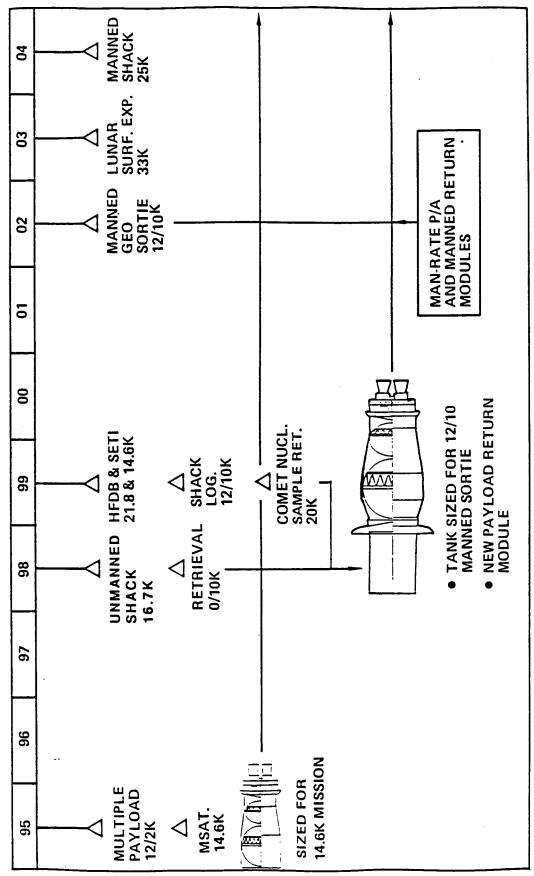


Figure 3.4-1 PRS OTV Misison Application

module will reenter and perform its aeromaneuver at least six minutes before the tankset reenters and is destroyed. Once the aeromaneuver is performed, the P/A module performs its correction and circularization burns using RCS to put itself into the proper LEO orbit to await return in the Shuttle.

For payload return missions, the difference in operations is that after the deorbit burn from GEO, the vehicle first targets and releases the return payload/aeroassist system, which performs its own aeromaneuver and returns to LEO. The tankset is then targeted and released followed by the P/A module. Again, a minimum of six minutes is allowed for separation of the vehicles on reentry. In this case, the return payload and the P/A module return to LEO to be retrieved by the Shuttle. In the case of manned missions, the empty crew module is launched with the OTV and the crew is picked up at the Space Station. Upon return, the crew is either returned in the Shuttle or returned to the Space Station. These operations are shown in figures 3.4-2 and 3.4-3.

3.4.3 Configuration Description

The configurations for the small and large GB partially reusable OTV's are shown in figures 3.4-4 and 3.4-5. Associated weight statements are given in Tables 3.4-2 and 3.4-3. The tankset structure consists primarily of GR/EP honeycomb sandwich enclosing strut-supported aluminum tanks, much like the fully reusable vehicle. Unlike the fully reusable system, however, the tank diameter is not constrained to the shuttle bay diameter, and the LH2 tank can be spherical and lighter weight. The LO2 tank is comprised of two elliptical domes for volumetric efficiency.

The P/A module contains all of the major subsystems including main propulsion, auxiliary propulsion, electrical power, guidance and navigation, and data handling and excludes only structure and tankage. Main propulsion thrust is provided by two advanced expander cycle engines having a vacuum thrust of 7000 lbf each. These are sized by applying a 0.12 thrust-to-weight factor to the large manned servicing mission for which the large tankset is sized. The auxiliary propulsion system utilizes hydrazine thrusters like that on the fully reusable OTV, but includes four 100 lbf thrusters on the aft end to perform the necessary post-aero correction and circularization delta V's. Like the fully re-usable system, the PRS power is provided by O2/H2 fuel cells, and the same avionics subsystems are used. Thermal control consists of MLI on the propellant tanks and FRSI around the engine cavity to protect the sensitive avionics and structure from radiation heating from the engine nozzle. Because of the short length of the P/A modules, up to five can be returned in the Shuttle cargo bay. Therefore, the P/A modules wait on-orbit for up to 70 days for the Shuttle return. Like the fully reusable

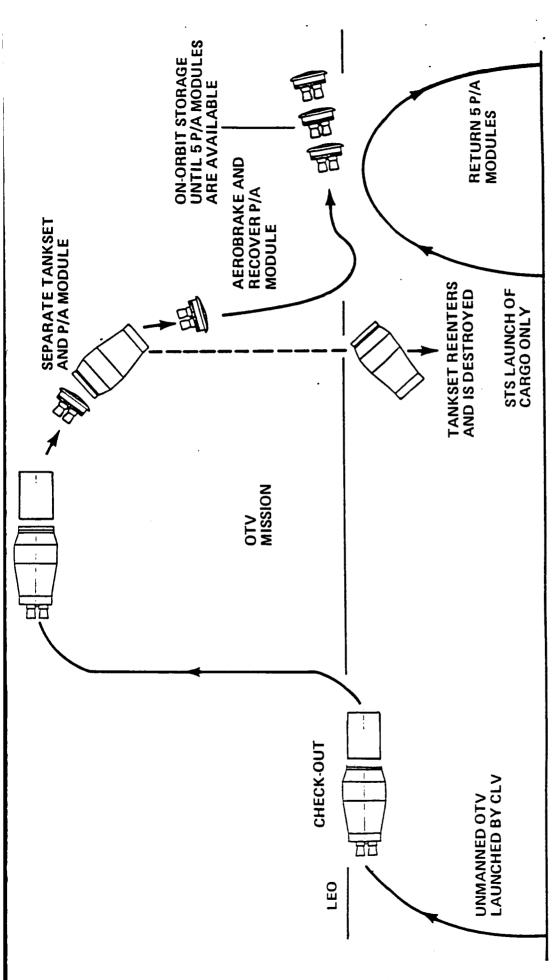


Figure 3.4-2 PRS Flight Operations Payload Delivery Mission-Ground Based

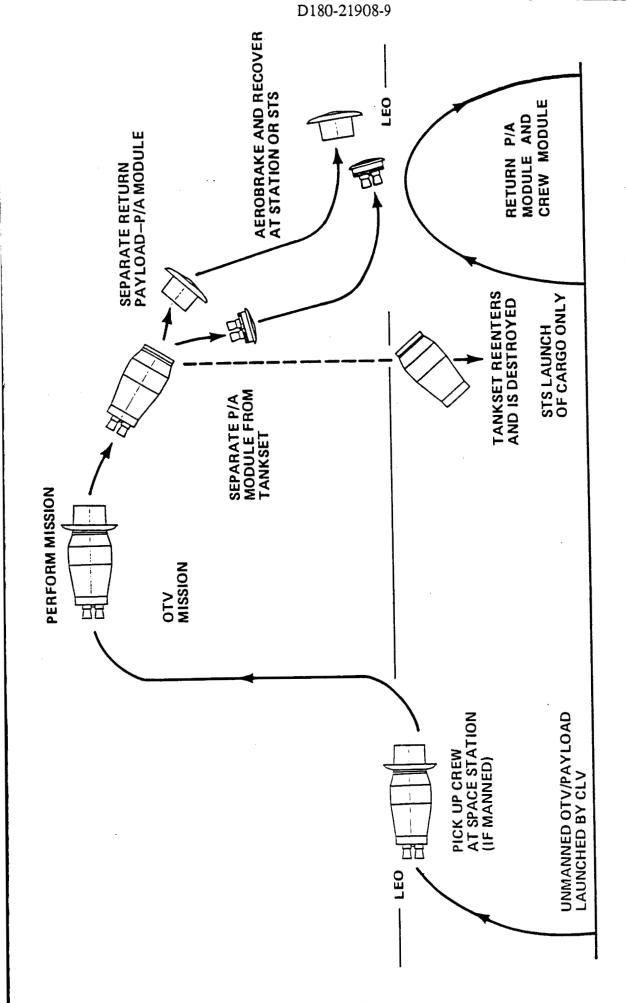


Figure 3.4-3 PRS Flight Operations Payload Return Mission—Ground Based

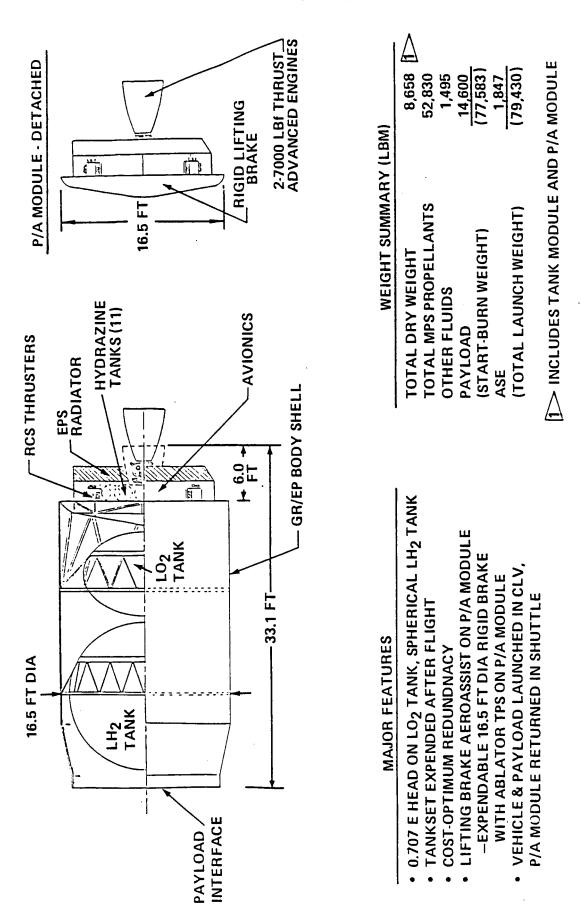


Figure 3.4-4 Small GB Partially Reusable OTV Configuration

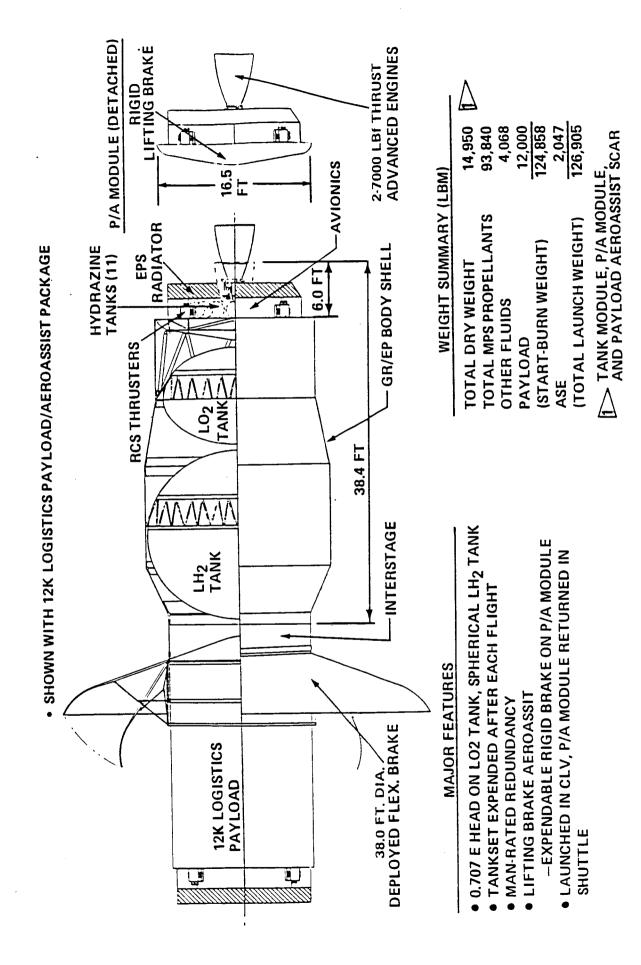


Figure 3.4-5 Large GB Partially Reusable OTV Configuration

MS TANK MODULE P/A M TANK MODULE P/A M 1,536 856 856 0 1,536 856 0 0 1,536 0 0 1,536 0 0 1,536 0 0 1,536 0 0 1,536 0 0 1,536 0 0 1,536 0 0 1,536 0 0 0 0 1,536 0 0 0 0 0 0 0 0 0 0 0 0 0	I dollar 3.4.5 of the state of	WEIGHT (LBM)	(LBM)
1,536 895 895 805 806 806 806 806 806 806 806 806 806 806		TANK MODULE	P/A MODULE
1,536 895 895 895 896 896 896 896 896 896 896 896 896 896	STURES AND MECHANISMS	2,439	895
## ## ## ## ## ## ## ## ## ## ## ## ##	BODY STRUCTURE	1,536	895
## ## ## ## ## ## ## ## ## ## ## ## ##	TANKAGE	856	0
.) 0 0 529 	MET/DEB SHIELDING		
## PROL ## PRO	16.5 FT	1	816
ROL 220 287	STRUCTURE	0	529
ROL 220 381 0 0 0 0 0 0 0 0 0	ERMAL PROTECTION		,
381 0 0 0 61 41 471 471 (3,613) 530 530 60 61 61 61 61 61 61 61 61 61 61	۵	220	165
## To be a second of the control of	I PROPULSION, LESS ENGINES	381	404
A HANDLING A HANDLING BING GROWTH DING GROWTH D IN RESIDUAL WEIGHTS) INCLUDING FPR) A 71 471 471 (3,613) 530 0 (4,143)	MAIN ENGINES (2 – 7000 LBF ASE)	0	482
A HANDLING A HANDLING A11 471 471 A71 A71 A71 A71 A71	AUXILIARY PROPULSION	0	368
A HANDLING A HANDLING A HANDLING A T	GUIDANCE AND NAVIGATION	0	141
#171 471 471 471 530	COMMUNICATIONS AND DATA HANDLING	61	301
DING GROWTH RESERVES) DING GROWTH DING GROWTH DING GROWTH INCLUDING FPR) INCLUDING FPR)	ELECTRICAL POWER	41	998
DING GROWTH RESERVES) DING GROWTH DING GROWTH DING GROWTH INCLUDING FPR) INCLUDING FPR)	WEIGHT GROWTH	471	209
DING GROWTH RESERVES) DING GROWTH DING GROWTH INCLUDING FPR) (4,143) (4,143) (1,143) (1,143) (2,143) (3,143) (4,143) (4,143) (4,143) (4,143) (4,143) (4,143) (4,143) (4,143)	(DRY WEIGHT)	(3,613)	(5,045)
DING GROWTH RESERVES) DING GROWTH DING GROWTH INCLUDING FPR) (4,143) (4,143) (4,143) (1,143)	RESIDUALS	530	201
RESERVES) DING GROWTH D IN RESIDUAL WEIGHTS) INCLUDING FPR) (4,143)	JETTISONABLE ITEMS, INCLUDING GROWTH	0	-938
DING GROWTH D IN RESIDUAL WEIGHTS) INCLUDING FPR)	(EOM WEIGHT, EXCLUDING RESERVES)	(4,143)	(4,308)
D IN RESIDUAL WEIGHTS) INCLUDING FPR) INCLUDING FPR)	JETTISONABLE ITEMS, INCLUDING GROWTH		+5,081
D IN RESIDUAL WEIGHTS) INCLUDING FPR) INCLUDING FPR)	EPS REACTANTS		80
INCLUDING FPR)	PRESSURANTS (RCS INCLUDED IN RESIDUAL WEIGHTS)		7
INCLUDING FPR)	RCS USABLE PROPELLANTS (INCLUDING FPR)		1,920
	MPS USABLE PROPELLANTS (INCLUDING FPR)		52,300
	(GROSS WEIGHT)		(969'69)

Table 3.4-3 OTV Weight Summary Large GB Partially Reusable OTV

WEIGHT (LBM)

	TANK MODULE	P/A MODULE
STRUCTURES AND MECHANISMS	3,902	895
BODY STRUCTURE	2,435	895
TANKAGE	1,420	0
MET/DEB SHIELDING	47	0
AEROASSIST DEVICE (16.5 FT. DIA.)	0	816
STRUCTURE	0	529
THERMAL PROTECTION	0	287
THERMAL PROTECTION AND CONTROL	322	165
MAIN PROPULSION, LESS ENGINES	472	460
MAIN ENGINES (2 – 7000 LB _F ASE)	0	482
AUXILIARY PROPULSION	0	390
GUIDANCE AND NAVIGATION	0	161
COMMUNICATIONS AND DATA HANDLING	99	382
ELECTRICAL POWER	99	1,021
WEIGHT GROWTH	723	649
(DRY WEIGHT)	(5,540)	(5,421)
RESIDUALS	836	201
JETTISONABLE ITEMS, INCLUDING GROWTH	0	-938
(EOM WEIGHT, EXCLUDING RESERVES)	(9,376)	(4,684)
JETTISONABLE ITEMS, INCLUDING GROWTH		+7,314
EPS REACTANTS		80
PRESSURANTS		7
RCS USABLE PROPELLANTS (INCLUDING FPR)		2,000
MPS USABLE PROPELLANTS (INCLUDING FPR)		93,000
		(690,/01)

OTV, extra avionics, RCS, and electrical power items are added to the baseline system to provide dormancy capability during the 70 days. This extra weight is explained in Table 3.4-4.

The P/A module performs the aeromaneuver by means of a rigid symmetric lifting brake. This brake is expendable and is covered with an ablative TPS. The rationale behind the choice of this particular design is shown in figure 3.4-6. If the brake is designed to be return in the Shuttle bay (<15 ft dia), the ballistic coefficient and concomitant aerodynamic heating is so high that an ablative TPS must be used. This TPS material leaves a charred surface that outgasses and return in the Shuttle may not be allowed. Additionally, the packaging of avionics and engines behind the brake would be difficult due to post-aeromaneuver heat soak through the TPS. On the other hand, if the brake is designed to be expendable, sizing the brake to minimize wake impingement on the P/A module yields a 16.5 foot diameter brake which still requires ablative TPS, and has a system weight of 816 lb. In order to use flexible TPS, the brake must be 21 feet in diameter with a system weight of 936 lb. Thus, the reference P/A module lifting brake is 16.5 foot diameter, with ablative TPS.

3.4.4 Payload Return Concepts

In designing a partially reusable OTV, the location and configuration of any return payloads becomes an issue. In the given mission model, the return payloads of particular interest include a 12klb logistics payload that is 22 ft long by 15 ft diameter and a 12klb manned servicing cab that is 10 ft long and 15 ft diameter. An analysis was performed to determine the best method of returning these two payloads. This trade is detailed in figure 3.4-7. One option is to place the payload between the P/A module and a large aerobrake and to attach the tankset on the front of this stack. The problem with this configuration is that the payload is not readily accessible and changeout of the payload is difficult. Also, propellant transfer lines are necessary with multiple disconnects for changeout.

The other option is to place the payload at the forward end of the vehicle and give it an independent set of avionics and propulsion to perform its own maneuvering and aeroassist. This option allows accessibility to the manned capsule and eases the logistics module changeout. Also, propellant transfer lines along the payload are not needed. Hence, this latter approach is the preferred option.

The aerobrake design features for each of the return modules are shown in figure 3.4-8, including those for the P/A module. The aerobrakes are all sized to minimize wake impingement on the module and are all expendable. The manned module aerobrake

Table 3.4-4 GB PRS--PJA Module On-Orbit Dormancy Provision

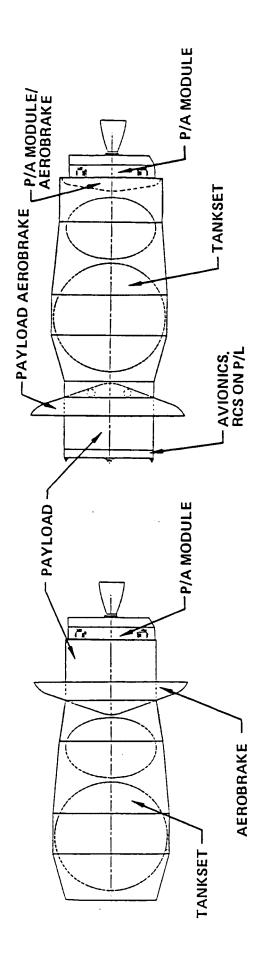
WEIGHT (LBM)	65	56	329	1	&	428
 P/A MODULE MUST STAY IN-ORBIT @ LEO FOR UP TO 70 DAYS TO AWAIT RETURN TO EARTH 	 RCS IMPACT - PROPELLANTS FOR ATTITUDE CONTROL AND ORBITAL MANEUVERING/RENDEVOUS —EXTRA HYDRAZINE TANK CAPACITY AND 45 LB PROPELLANT 	 AVIONICS IMPACT - SUN SENSOR, HORIZON SENSORS, ELECTRONICS 	• ELECTRICAL POWER - SOLAR ARRAYS, NICO BATTERIES	 MET/DEB SHIELD · SMALL EXPOSURE AREA OF CRITICAL ITEMS —EXISTING STRUCTURE DEEMED ADEQUATE 	THERMAL CONTROL - INSULATION ON SOLAR ARRAY COVERS	TOTAL WEIGHT

P/A MODULE MUST BE RETURNED IN SHUTTLE BAY **ALTERNATIVES:**

	SMALL DIAMETER	IETER	LARGE DIAMETER
SIZING CONSTRAINT	MAXIMUM SCB DIAMETER	WAKE IMPINGEMENT	SURFACE HEATING
BRAKE DIAMETER (FT)	15	16.5	21.0
BALLISTIC COEFFICIENT (PSF)	27.3	21.7	12.6
RIGID TPS TYPE	ABLATOR	ABLATOR	FRCI TILE
FLEX TPS TYPE	N/A	N/A	TABI
SHUTTLE RETURN IMPACT	DIFFICULT-ABLATOR	NO IMPACT-EXPEND	NO IMPACT-EXPEND
AVIONICS, EQUIP PACKAGING	DIFFICULT-SMALL DIAMETER	BETTER	BEST
TOTAL WEIGHT (LB)	670	816	936
RIGID STRUCTURE WT	409	529	396
FLEX SUPPORT STRUCTURE WT		ļ	204
RIGID TPS WT	261	287	185
FLEX TPS WT		-	151

USE SMALL 16.5 FT DIAMETER EXPENDABLE RIGID BRAKE

Figure 3.4-6 P/A Module Aerobrake Design Trade



PAYLOAD BETWEEN TANKSET AND P/A MODULE

- REQUIRES ONE AEROBRAKE, ONE SET OF AVIONICS AND RCS
 CANNOT DOCK CREW MODULE DIRECTLY
 - CANNOI DOCK CHEW MODULE DIRE
 FOR TRANSFER/SERVICING
- LOGISTICS PAYLOAD CHANGEOUT IS DIFFICULT
 MULTIPLE DISCONNECTS AND TRANSFER LINES REQUIRED IN PLUMBING

PAYLOAD WITH SEPARATE AEROASSIST AND RCS/AVIONICS

- REQUIRES TWO SETS OF AVIONICS, RCS, AND AEROBRAKES
- SERVICING

 SERVICING

 SOCIATIONS

 SOCIATIO
- LOGISTICS PAYLOAD CHANGEOUT EASIER
 ONE SET OF PLUMBING DISCONNECTS REQUIRED; NO

EXTRA TRANSFER LINES

PUT PAYLOAD ON FORWARD END, WITH SEPARATE AEROASSIST/PROPULSION PACKAGE

Figure 3.4-7 PRS Payload Return Concept Trade

			SOLETICE BANIOAN AEBOBBAKE
	P/A MODULE AEROBRAKE	MANNED MODULE AEROBRAKE	P/A MODULE AEROBRAKE MANNED MODULE AEROBRAKE LUGISTICS PATEUAD ALROBITATE
DIAMETER (FT) SIZING CONSTRAINT BALLISTIC COEFFICIENT BRAKE TYPE TPS TYPE	16.5 WAKE IMPINGEMENT 21.7 RIGID SHELL CORK ABLATOR	25.0 WAKE IMPINGEMENT 22.0 RIGID SHELL CORK ABLATOR	38.0 WAKE IMPINGEMENT 9.9 DEPLOYED FLEX BRAKE FSI/FRCI
TOTAL WEIGHT (LB) RIGID STR FLEX SUPPORT STR RIGID TPS FLEX TPS	816 529 287 	1527 846 681	2098 680 464 225 729

Figure 3.4-8 Aeroassisted Payload Return Aerobrake Design Features

is a rigid brake with ablative TPS because of the high ballistic coefficient. The logistics payload module has a lower ballistic coefficient and the brake can make use of flexible TPS. This brake system is also larger than 25 feet diameter and must be a flexible system that can be deployed.

The configuration of the manned module aeroassist package is shown in figure 3.4-9 and a summary weight statement is given in Table 3.4-5. For this system all subsystems are manrated and separate avionics, electrical power, and RCS capabilities are included.

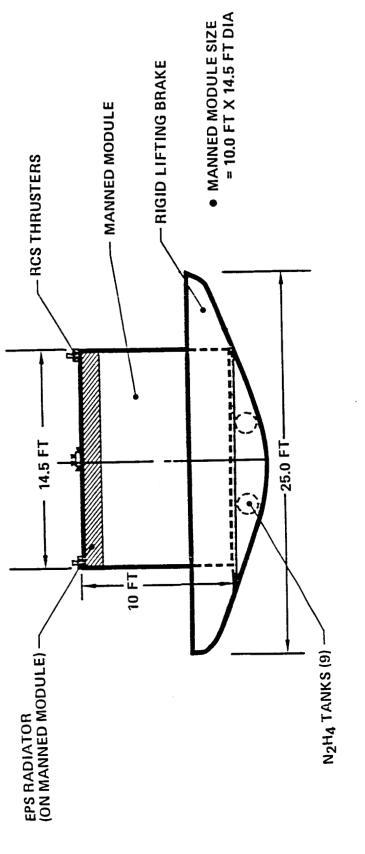
The configuration for the logistics module aeroassist package is shown in figures 3.4-10 and 3.4-11 and a summary weight statement is given in Table 3.4-6. In this case, the aerobrake is a deployable flexible lifting brake that is deployed using a motor-driven linkage assemble on each rib. For this system, the subsystems are not manrated but separate avionics, electrical power, and RCS capabilities are provided in a kitted P/A module.

3.4.5 Stage Launch and Return Concepts

The GB partially reusable vehicles are launched from the ground with the CLV, however, only the P/A modules are returned so they must be compatible with the Shuttle cargo bay. These concepts are shown in figure 3.4-12. For launch, the necessary ASE includes a payload-specific adaptor, a forward damping system, and fill/drain provisions. For return in the Shuttle, trunnion and keel fittings are built into the P/A modules to correspond with bridge fittings and latches installed in the Shuttle. Also included in the Shuttle return ASE are electronics and instrumentation for monitoring the P/A module systems during the return to earth. These ASE weights are presented in Table 3.4-7.

3.5 GB EXPENDABLE OTV - ALL-PROPULSIVE RETURN

The differences between the GB fully reusable and GB expendable OTV subsystems are delineated in Table 3.5-1. In both cases the tanks are launched full so the body structure is designed to take the launch loads. However, the tanks on the expendable system are only used once so they are designed for a single mission service life and are lighter weight. Due to the short duration of delivery missions for the expendable vehicle, electrical power is provided by batteries rather than the more expensive fuel cell systems. Also, because of the single mission life requirement, health monitoring instrumentation is reduced in the expendable vehicle system. Because the missions are performed all-propulsively, aeroassist devices are not required on the expendable vehicle.



	3,747 1,710 68 10,000	(10,050
WEIGHT SUMMARY (LBM)	TOTAL DRY WEIGHT TOTAL MPS PROPELLANTS OTHER FLUIDS PAYLOAD	(STAGED WEIGHT)

ELECTIRCAL POWER PROVIDED BY FUEL CELLS

ABLATOR TPS

• N₂H₄ SYSTEM FOR ΔV MANEUVERS

MAN-RATED SUBSYSTEMS

RIGID EXPENDABLE LIFTING BRAKE WITH

MAJOR FEATURES

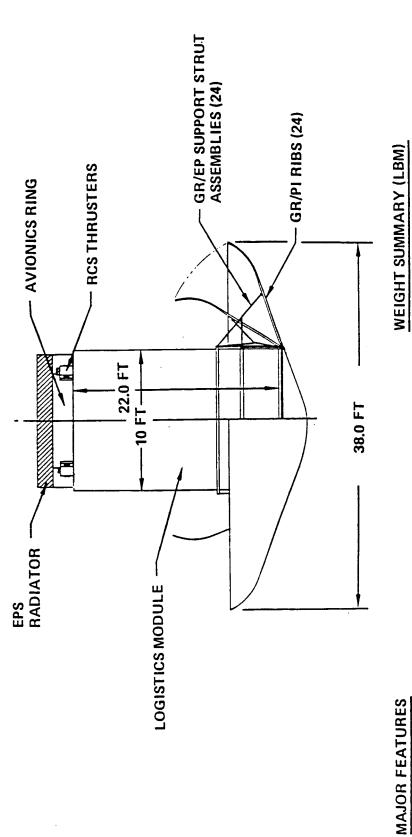
Figure 3.4-9 10K Manned Module Return Aeroassist Package Configuration

Table 3.4-5 Weight Summary 10K Manned Capsule Aerobrake Scar

MAN-RATED SUBSYTEMS

WEIGHT (LBM)

445 87 0	338 135	310	1,527	441	(3,747)	78	10,000	-1,662	(12,163)	+1,662	0	1,700	(15,525)	242	(15,767)
STRUCTURE AND MECHANISMS THERMAL CONTROL MAIN PROPULSION	AUXILIARY PROPULSION GUIDANCE AND NAVIGATION	COMMUNICATIONS AND DATA HANDLING	AEROASSIST PACKAGE	WEIGHT GROWTH	(SCAR DRY WEIGHT)	RESIDUALS	RETURN PAYLOAD WEIGHT	JETTISONABLE ITEMS, INCLUDING GROWTH	(EOM WEIGHT, EXCLUDING RESERVES)	JETTISONABLE ITEMS, INCLUDING GROWTH	USABLE MAIN PROPELLANTS	USABLE AUXILIARY PROPELLANTS	(STAGED WEIGHT)	INTERSTAGE STRUCTURE	(TOTAL PAYLOAD WEIGHT)



TOTAL DRY WEIGHT TOTAL RCS PROPELLANTS	4,375 1,810
OTHER FLUIDS	89
PAYLOAD	10,000
(STAGED WEIGHT)	16,253

N₂H₄ RCS SYSTEM FOR AV MANEUVERS COST-OPTIMUM REDUNDANCY P/A MODULE IS REUSABLE

ELECTRICAL POWER PROVIDED BY FUEL CELLS

-ENTIRE BRAKE IS EXPENDED TO ALLOW **DEPLOYABLE FLEXIBLE LIFTING BRAKE**

RETURN IN SHUTTLE

Figure 3.4-10 10K Logistics Payload Return Aeroassist Package Configuration

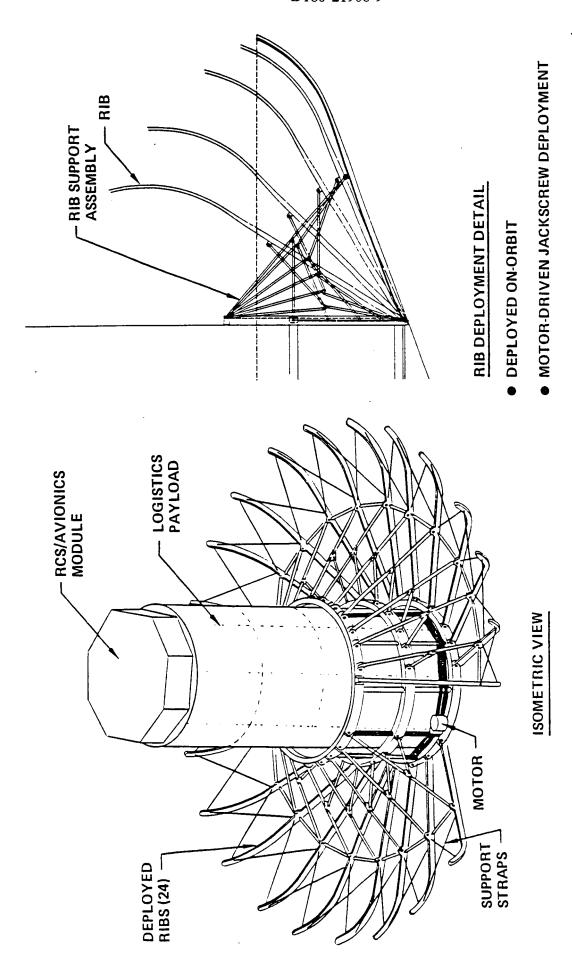


Figure 3.4-11 Logistics Payload Aeroassist Package Configuration Detail

COST OPTIMUM SUBSYSTEMS

WEIGHT (LBM)	445	0	342	239	504	2,098	545	(4,375)	8/	10,000	-2,145	(12,308)	+2,145	0	1,800	(16,253)	242	(16,495)
	STRUCTURE AND MECHANISMS	MAIN PROPULSION	AUXILIARY PROPULSION	GUIDANCE AND NAVIGATION	COMMUNICALIONS AND DATA HANDLING ELECTRICAL POWER	AEROASSIST PACKAGE (38.0 ft. dia.)	WEIGHT GROWTH	(SCAR DRY WEIGHT)	RESIDUALS	RETURN PAYLOAD WEIGHT	JETTISONABLE ITEMS, INCLUDING GROWTH	(EOM WEIGHT, EXCLUDING RESERVES)	JETTISONABLE ITEMS, INCLUDING GROWTH	USABLE MAIN PROPELLANTS	USABLE AUXILIARY PROPELLANTS	(STAGED WEIGHT)	INTERSTAGE STRUCTURE	(TOTAL PAYLOAD WEIGHT)

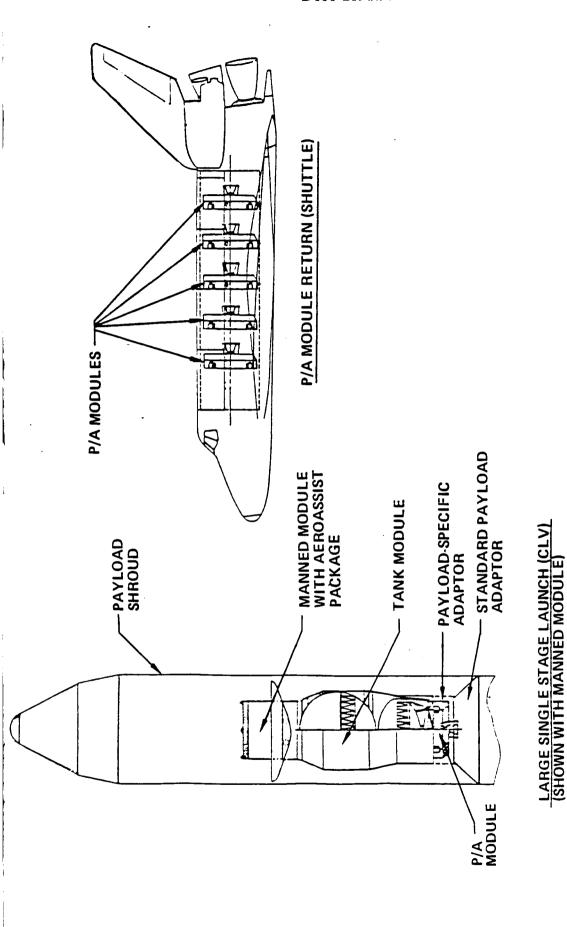


Figure 3.4-12 GB PRS Launch and Return Concepts

Table 3.4-7 GB PRS Stage Launch and Return ASE

		WEIGHT (LBM)	
-	CLV LAUNCH SMALL STAGE	CLV LAUNCH LARGE STAGE	SHUTTLE RETURN 5 P/A MODS
● COMMON GOV'T FURN. EQUIP	<u></u>	<u>_</u>	<u></u>
● FITTING ALLOWANCE	1	ı	ı
CABLING, MISC.	l		ı
 PAYLOAD SUPPORT EQUIP 	100	100	
 ATTACH FTGS. 		ı	ı
PAYLOAD KITS	100	100	ı
CONTRACTOR EQUIP	I	l	1
STAGE SUPPORT EQUIP.	1747	1947	4975
 ATTACH FTGS. 	ı	l	4019
• MISC. GFE	ı	ı	ı
 CONTRACTOR EQUIP. 	1747	1947	926
(TOTAL)	1847	2047	4975

WEIGHTS ARE EQUIVALENT WEIGHTS TO ORBIT
 SHUTTLE RETURN INCLUDES SUPPORT FOR FIVE P/A MODULES

(1) INCLUDED IN LAUNCH VEHICLE WEIGHT

(2> CHARGED TO UP PAYLOAD

Table 3.5-1 GB FRS and Expendable Subsystem Comparison

ITEM	GB FULLY REUSABLE OTV	GB EXPENDABLE OTV
• BODY STRUCTURES	GR/EP BODY SHELL DESIGNED FOR LAUNCH LOADS	SAME
• TANKAGE	STRUT-SUPPORT 2219-T87 ALUM DESIGNED FOR 45 MISSION LIFE	SAME, BUT DESIGNED FOR 1 MISSION LIFE
• MET/DEB PROTECTION	PROVIDED BY GR/EP BODY SHELL/MLI 9995 PROB. OF NO. TANK IMPACT	SAME
• THERMAL PROTECTION & CONTROL	FSI ON BODY FOR HI-TEMP BALLUTE; MLI ON TANKAGE; FUEL CELL RADIATORS	NO FSI ON STAGE: MLI-SAME FUEL CELL RADIATORS ONLY ON LG. STAGE
• MAIN PROPULSION	2-6000 LBf ADVANCED ENGINES	2-8000 LBf ADVANCED ENGINES
• AUXILIARY PROPULSION	N ₂ H ₄ EXTERNAL PRESS. DIAPHRAGM TANKS, SAME 25 LBf THRUSTERS	SAME
• GUIDANCE & NAVIGATION	IMU, STAR TRACKER, GPS	NO GPS RECEIVER/PROCESSOR
• COMMUNICATIONS/DATA	TDRS TRANSPONDER, INTEGRATED DMS, LOADING & HEALTH INSTRUMENTATION	REDUCED INSTRUMENTATION FOR HEALTH MONITORING
• ELECTRICAL POWER	2.0 KW NOM O2/H2 FUEL CELLS SOLAR ARRAYS FOR ON-ORBIT DORMANCY	SILVER-ZINC BATTERIES ON SMALL STAGE, FUEL CELLS ON LARGE STAGES
• AEROASSIST	1500° B/W TEMP. EXPENDABLE BALLUTE	NO AEROASSIST DEVICE ON STAGE

3.5.1 Mission Application

The evolutionary path of the ground-based expendable vehicle, as applied to the mission model, is shown in figure 3.5-1. For the delivery missions, the vehicle can be very small due to the fact that the vehicles are not returned from the higher orbit. Three options for the evolutionary path of the expendable OTV were evaluated; (1) size the vehicle to do the small delivery mission, (2) size the vehicle for the large mission and offload for the smaller mission, and add an auxiliary tank to do the large manned missions, and (3) size two identical stages to do the worst-case mission in a dual stage configuration. Figure 3.5-2 shows the performance comparison of these three options using RL-10-IIIB derivative engines. It is seen that even the optimum approach, that of the dual stage system, exceeds the 150klb limit of the CLV. As is shown in figure 3.5-2, it was found that the better performance of the advanced space engine (I_{SD} = 483 versus 470 lbf - sec/lbm) puts the dual stage system within the launch vehicle capability. This, then, becomes the preferred option. The small vehicle is sized for a usable propellant loading of 30,500 lb, and the large vehicle is sized for a usable propellant loading of 58,100 lb. For delivery missions larger than 14.6klb delivery, one of the large stages is used in an offloaded condition.

3.5.2 Operational Description

Both the small and the large expendable vehicles are launched from the ground in the unmanned cargo launch vehicle with the payload attached. For delivery missions, the stage delivers the payload to orbit then performs a maneuver to place it in a disposal orbit at GEO +850 nm as depicted in figure 3.5-3. This approach allows the stage to be much smaller because it does not need to return to LEO.

For payload return operations, as shown in figure 3.5-4, the dual stage system with payload is launched in the CLV. If the mission is to be manned, the crew is picked up at the Space Station and the mission is performed. The first perigee burn is performed by the first stage of the system, which is then jettisoned to reenter the atmosphere and be destroyed. The second stage, with payload, completes the mission and performs an all-propulsive delta V maneuver to return to LEO. The crew and return payload are returned to the Space Station or to the Shuttle and then the OTV stage is deorbited and destroyed.

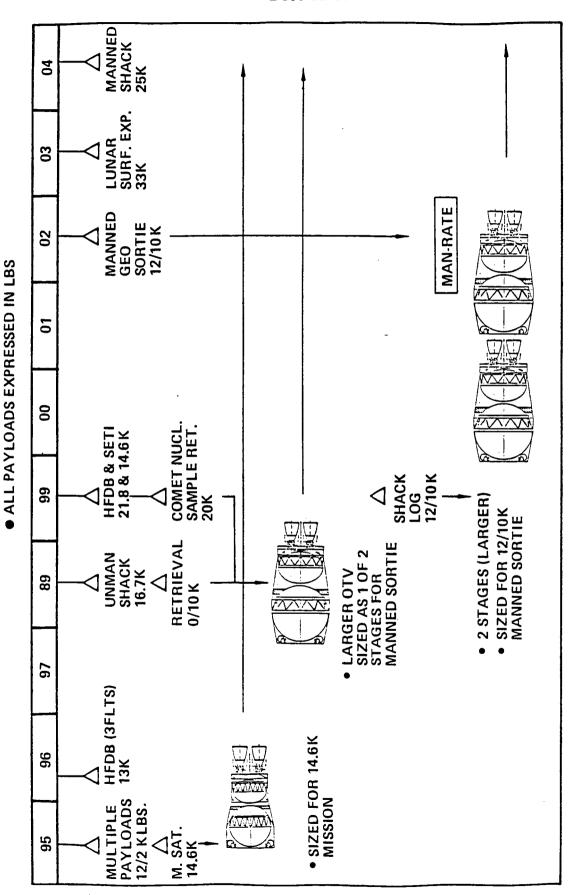


Figure 3.5-1 Expendable OTV Mission Application

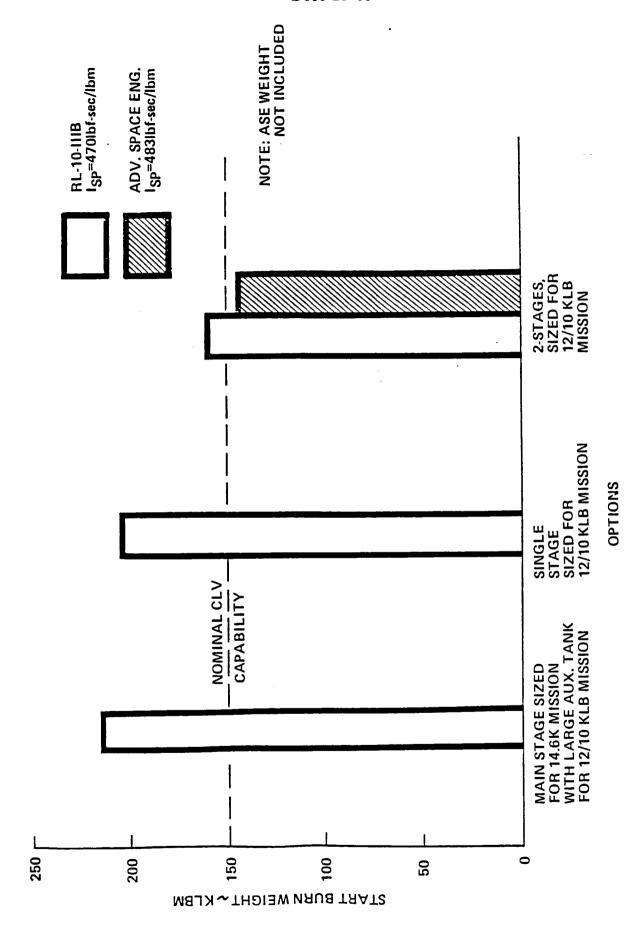


Figure 3.5-2 Start Burn Weights for 12/10 Manned Servicing Mission

Figure 3.5-3 Expendable OTV Flight Operations Delivery Missions

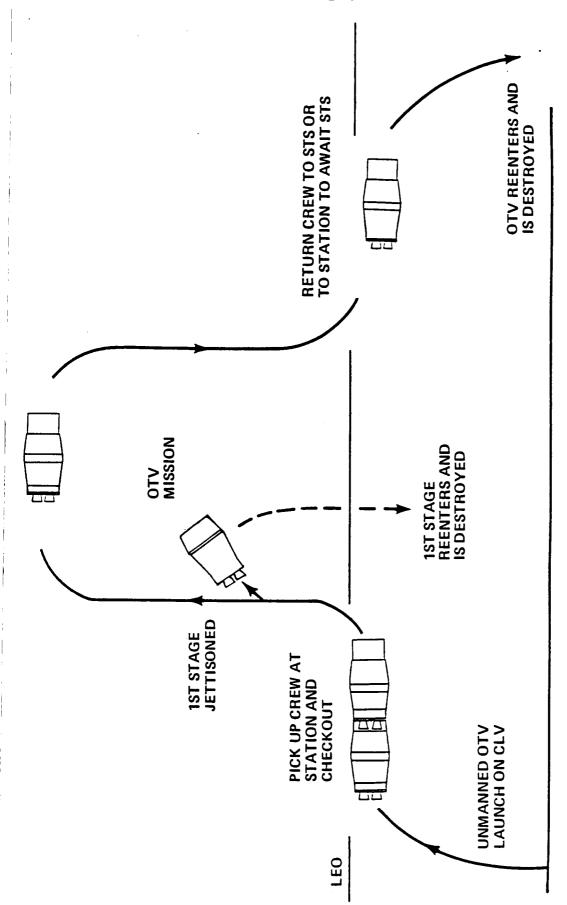


Figure 3.5-4 Expendable OTV Flight Operations All-Propulsive Payload Return Missions

3.5.3 Configuration Description

The configurations for the small and large GB expendable OTV's are shown in figures 3.5-5 and 3.5-6, respectively, with associated weight summaries given in Tables 3.5-2 and 3.5-3. The body structure consists primarily of GR/EP honeycomb sandwich enclosing strut-supported aluminum tanks. Like the partially reusable vehicles, tank diameter is not constrained to be returned in the Shuttle allowing the LH2 tank to be spherical and the LO2 tank to be elliptical.

In the small vehicle, all subsystems have cost-optimum redundancy and electrical power is provided by lower-cost silver-zinc batteries rather than fuel cells. Electrical power on the large vehicle is provided by O2/H2 fuel cells with active thermal control provisions. Main propulsion thrust for both sizes of vehicles is provided by two advanced expander-cycle engines having a rated vacuum thrust of 8000 lbf each. These are sized by applying a 0.12 thrust-to-weight ratio of the large manned servicing mission start-burn weight.

The auxiliary propulsion and the avionics systems are similar to those on the fully reusable vehicle. Thermal control for the main propellant tanks is provided by MLI.

3.5.4 Stage Launch Concepts

The launch concepts for the single small stage with payload and the dual stage configuration are shown in figure 3.5-7. In the case of the small stage, the forward bearing reaction system (FBRS) serves as a dynamic damping system. In the case of the dual stage system, the FBRS reacts lateral loads from the stages into the shroud during part of the launch and reacts loads from the shroud into the stages at other times. The analysis dealing with the interaction of these elements is described later. Launch ASE includes a payload-specific adaptor, forward-bearing reaction systems, and fill/drain provisions. For the two stage system, fill/drain provisions must be included for the second stage as well as the first stage. These items are reflected in the ASE weights shown in Table 3.5-4.

A detailed structural analysis was performed to understand the interaction of the dual-stage system and the payload shroud during the launch phase. In particular, it is desirable to minimize the loading on the OTV in a two stage configuration in order to minimize the weight. Figure 3.5-8 illustrates two options relating to the design of two-stage system to be launched in a CLV when the system is subjected to large lateral loads during launch. Figure 3.5-9 shows the assumed launch configuration and launch profile of a two stage launch vehicle consisting of a reusable flyback booster and a partially reusable payload/tank module. The major events in the flight profile include maximum

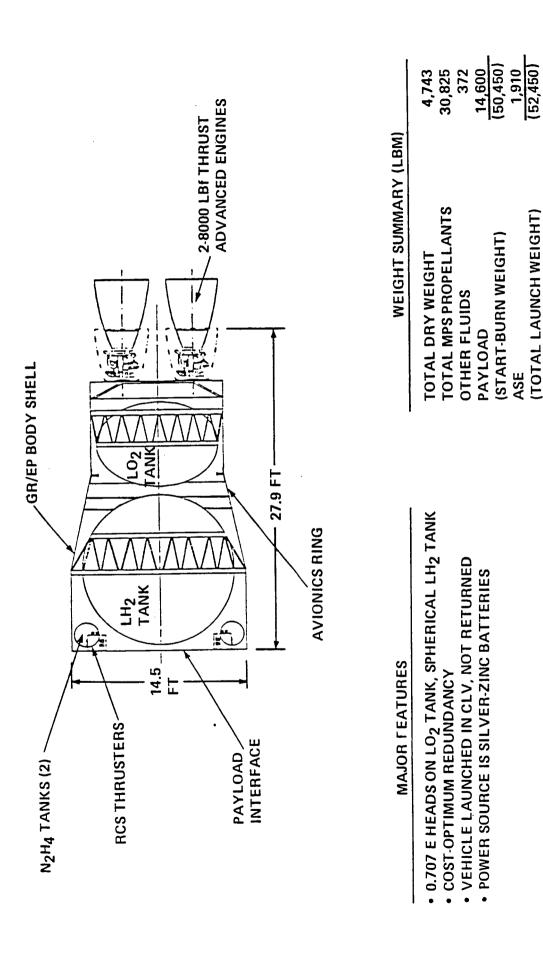


Figure 3.5-5 Small GB Expendable OTV Configuration

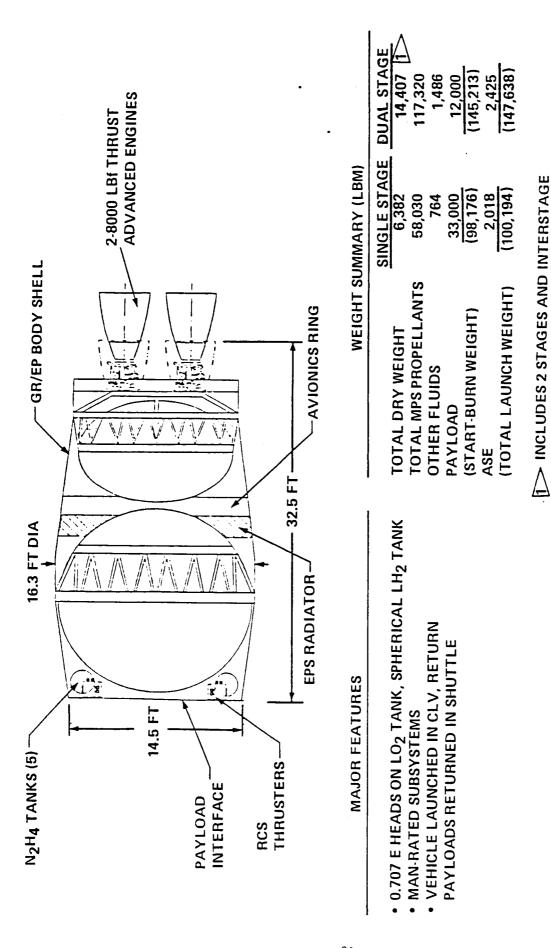


Figure 3.5-6 Large GB Expendable OTV (All-Propulsive P/L Return) Configuration

PROVIDED BY BODY SHELL

Table 3.5-2 OTV Weight Summary Small GB Expendable OTV

COST.OPTIMUM REDUNDANCY

WEIGHT (LBM)

1843	1295	548	0	151	506	512	137	22	334	645	299	(4743)	366		(2109)	2	8	30,500 30,500 (35,967)
	STRUCTURES AND MECHANISMS	BODY STRUCTURE	TANKAGE	MET/DEB SHIELDING	THERMAL PROTECTION AND CONTROL	MAIN PROPULSION, LESS ENGINES	MAIN ENGINES (2 - 8000 lbf ASE)	AUXILIARY PROPULSION	GUIDANCE AND NAVIGATION	COMMUNICATIONS AND DATA HANDLING	ELECTRICAL POWER	WEIGHT GROWTH	(DRY WEIGHT)	RESIDUALS	(EOM WEIGHT, EXCLUDING RESERVES)		EPS REACTANTS	PRESSURANTS RCS USABLE PROPELLANTS (INCLUDING FPR) MPS USABLE PROPELLANTS (INCLUDING FPR) (GROSS WEIGHT)

Table 3.5-3 OTV Weight Summary Large GB Expendable OTV

WEIGHT (LBM)

	Cost-Optimum	Man-Rated
STBHCTHRES AND MECHANISMS	2981	2981
BODY STRIICTURE	2049	2049
TANKAGE	885	885
MET/DEB SHIELDING	. 47	47
THERMAL PROTECTION AND CONTROL	322	322
MAIN PROPULSION, LESS ENGINES	586	664
MAIN ENGINES (2-8000 lbf ASE)	512	512
AUXILIARY PROPULSION	218	240
GUIDANCE AND NAVIGATION	55	110
COMMUNICATIONS AND DATA HANDLING	337	420
ELECTRICAL POWER	. 571	733
WEIGHT GROWTH	800	847
(DRY WEIGHT)	(6382)	(6859)
RESIDUALS	631	631
(EOM WEIGHT, EXCLUDING RESERVES)	(7013)	(7460)
EPS REACTANTS	80	80
PRESSURANTS	æ	8
RCS USABLE PROPELLANTS (INCLUDING FPR)	. 096	096
MPS USABLE PROPELLANTS (INCLUDING FPR)	58,100	58,100
(GROSS WEIGHT)	(66,161)	(809'99)

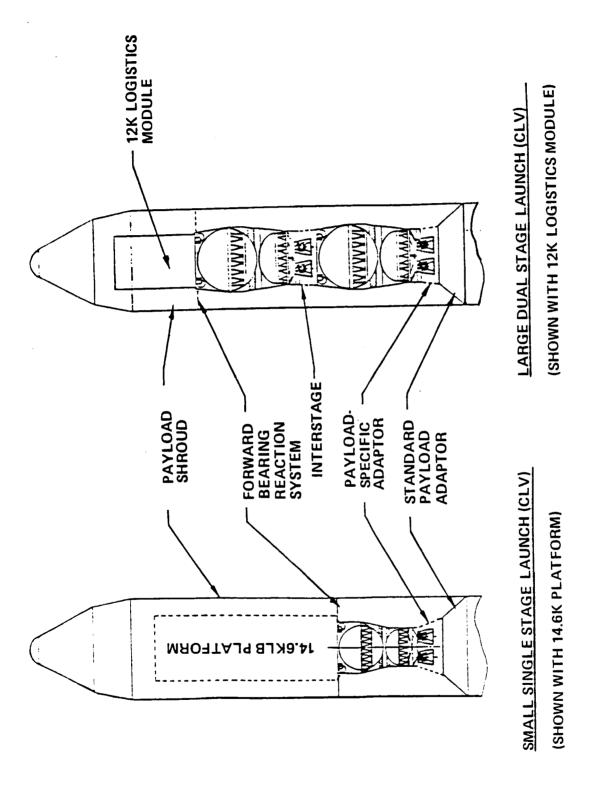


Figure 3.5-7 GB Expendable—Launch Concepts

Table 3.5-4 GB Expendable Stage Launch ASE

		WEIGHT (LBM)	
	CLV LAUNCH 1-STAGE (SMALL)	CLV LAUNCH 1-STAGE (LARGE)	CLV LAUNCH 2-STAGE (LARGE)
● COMMON GOV'T FURN. EQUIP	<u> </u>	<u> </u>	A I
● FITTING ALLOWANCE	ı	ı	1
• CABLING, MISC.	i	ı	I
 PAYLOAD SUPPORT EQUIP 	100	100	100
• ATTACH FTGS.	1	ı	I
PAYLOAD KITS			I
• CONTRACTOR EQUIP	100	100	100
STAGE SUPPORT EQUIP.	1810	1918	2325
● ATTACH FTGS.	ı	· I	ı
● MISC. GFE	1	ı	i
 CONTRACTOR EQUIP. 	1810	1918	2325
(TOTAL)	1910	2018	2425

WEIGHTS ARE EQUIVALENT WEIGHTS TO ORBIT
 DUAL STAGE LAUNCH ASE INCLUDES A LOAD-BEARING FORWARD REACTION SYSTEM AND FILL/DRAIN PROVISIONS FOR SECOND STAGE

□ INCLUDED IN LAUNCH VEHICLE WEIGHT

MUST BE SUPPORTED IN CARGO LAUNCH VEHICLE PAYLOAD MODULE SHROUD TWO-STAGE GROUND-BASED OTV WITH COMMON 1 ST & 2ND STAGE MODULES

- WITH MAXIMUM AXIAL LOADS DUE TO ASYMMETRIC LAUNCH VEHICLE CONFIGURATION OTV/PAYLOAD STACK IS SUBJECTED TO LARGE LATERAL LOADS IN CONJUNCTION
- TRADE TWO OPTIONS FOR REACTING LATERAL LOADS:
- OPTION 1 CANTILEVER LATERAL LOADS TO BASE OF SHROUD
- OPTION 2 USE FORWARD BEARING REACTION SYSTEM (FBRS) TO REACT PORTION OF LATERAL LOAD INTO SHROUD

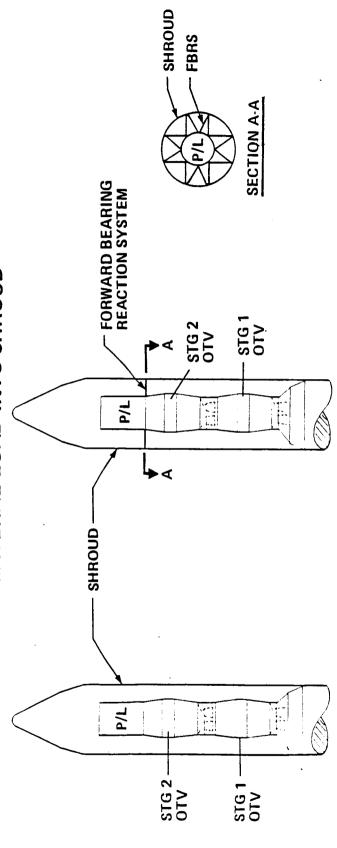


Figure 3.5-8 Two-Stage GB OTV/CLV Integration

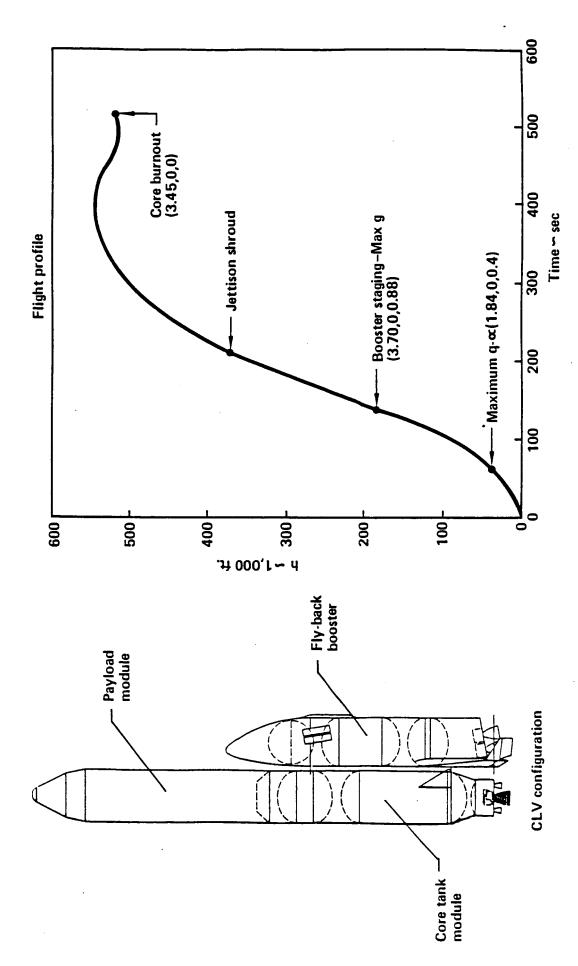


Figure 3.5-9 GB OTV/CLV Configuration and Flight Profile

q-alpha when the maximum axial and lateral acceleration is experienced, shroud jettison when the shroud and FBRS are jettisoned, and second stage burnout when large axial loads are experienced. The critical loading conditions experienced by the shroud an payload are delineated in figure 3.5-10. One option for reacting the lateral loads experienced during launch is to cantilever the payload stack completely at the base of the stack. The other option is to react some of the loads into the payload shroud by using a FBRS.

For the first option, the payload stack was treated as a simple cantilever beam and the first and second stages were assumed identical. For the second option, the payload stack and shroud were treated as interdependent beams with a compatible displacement at the FBRS location. Table 3.5-5 summarizes the analysis methods used to study the reaction between the shroud and payload stack. The interaction is shown graphically in figure 3.5-11 using the average thickness of the shroud and OTV body shell as the sizing criteria. Consider the design point on the chart (flagnote 1) which is sized for max qalpha conditions. It can be seen that, at max q-alpha conditions, a positive margin is available (flagnote 2). This means that, if a nominal shroud is used and if the FBRS and OTV body shell are designed for maximum q-alpha conditions, the system will be stiff enough to react the loads at max q-alpha. Figure 3.5-12 summarizes these findings. IF a FBRS is not used, the weight penalty to the OTV will be 900 lb. With the FBRS, and using a nominal shroud, the penalty is only 200 lb as compared to a vehicle sized to take only the axial loads at burnout. An increase in the shroud weight does not improve the OTV weight significantly and a decrease in the shroud weight would result in a shroud that is dependent upon the payload for support during maximum aero loading conditions.

In conclusion, it can be seen that cantilevering the payload stack entirely causes large moments at the base of the stack and forces a large weight penalty on the OTV. Use of the FBRS significantly reduces the moments in the stack and minimizes the OTV body shell weight, using a nominal shroud design. Further optimization of the system could be accomplished by adding an additional FBRS and by optimizing the FBRS location. By doing these things, it could be possible to approach the nominal body shell weight needed to support the system at maximum axial loads following jettisoning of the shroud. These conclusions are summarized in Table 3.5-6.

3.6 GB EXPENDABLE OTV - AEROASSIST RETURN PAYLOADS

An alternative to returning payloads all-propulsively with an expendable system is to return the payloads using aeroassist. With this system, the logistics module or manned module would be returned with the same type of aeroassist packages as shown

SHROUD NOMINALLY SIZED TO WITHSTAND MAX q-a AERO LOADS (t=665 SEC)

Fx = 1.84 g (AXIAL)

 $F_y = 0$ (LATERAL) $F_z = 0.04 g$ (LATERAL)

V = 113,550 LB (INTEGRATED LATERAL AERO LOAD ON SHROUD)

OTV BODY SHELL DESIGNED TO WITHSTAND MAX LATERAL - MAX AXIAL ACCELERATION LOAD CONDITION JUST PRIOR TO FLYBACK BOOSTER MODULE BURNOUT (t=1415 SEC)

Fx = 3.70 g (AXIAL)

Fy = 0 (LATERAL)

Fz = 0.88g (LATERAL)

V = O (INTEGRATED LATERAL AERO LOAD ON SHROUD)

Figure 3.5-10 Critical Loading Conditions on Shroud/Payload

- OPTION 1 CANTILEVER LOADS TO BASE OF SHROUD
- IDEALIZE AS SIMPLE CONTILEVER BEAM
- CRITICAL LOAD CONDITION IS MAX LATERAL—MAX AXIAL ACCELERATION (t = 1415 SEC)
- 1st & 2nd STAGE OTV's ARE IDENTICAL MODULES SIZED FOR MAXIMUM MOMENTS ON PAYLOAD STACK
- OPTION 2 USE FORWARD BEARING REACTION SYSTEM (FBRS) TO REACT PORTION OF LATERAL LOAD INTO SHROUD
- NOMINAL SHROUD SIZING AT MAXq-α(t =665 SEC)
- MAX LATERAL AERO LOADS
- LATERAL G-FORCES ARE NEGLIGIBLE
- ANALYZE AS RELATIVE STIFFNESS PROBLEM WITH PAYLOAD STACK & SHROUD IDEALIZED AS BEAMS HAVING COMPATIBLE DISPLACEMENTS AT FBRS LOCATION
- OTV BODY SHELL SIZED FOR MAX LATERAL MAX AXIAL LOAD (t = 1415 SEC)
- MAX AXIAL & BENDING ON P/L STACK
- AERO LOADS ON SHROUD ARE NEGLIGIBLE
- SHROUD MUST WITHSTAND FBRS AT MAX-G LOADING & P/L STACK MUST WITHSTAND FBRS AT MAX AERO LOADING



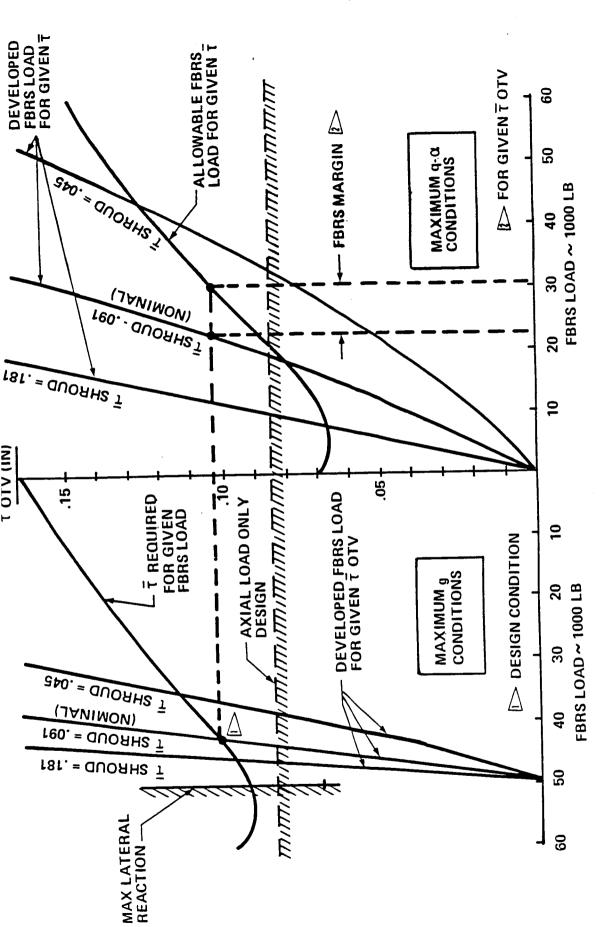


Figure 3.5-11 Two-Stage Expendable OTV Launch Body Shell Sizing Analysis

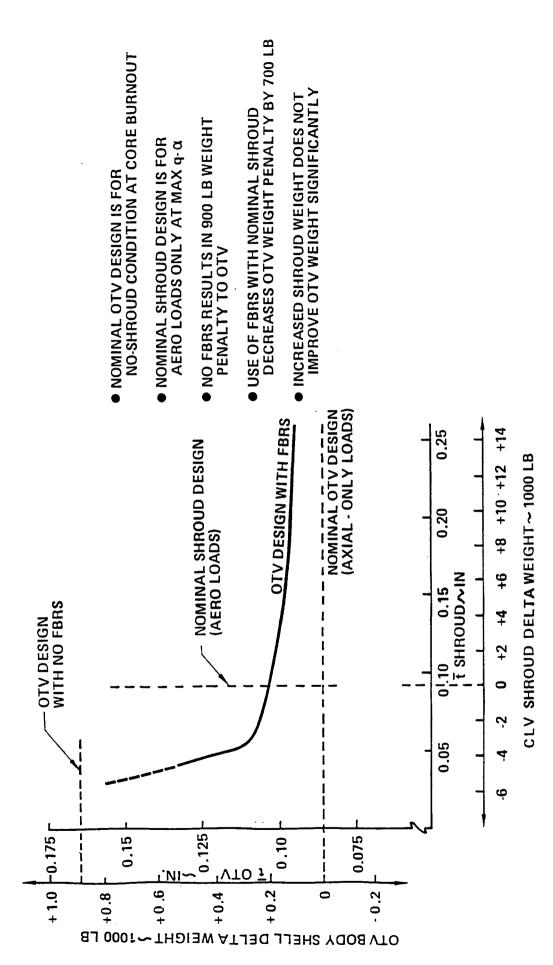


Figure 3.5-12 Two Stage Expendable OTV Launch OTV/CLV Weight Sensitivity

Table 3.5-6 Two Stage Launch—Conclusions and Recommendations

- CANTILEVERING (OPTION 1) CAUSES LARGE MOMENTS AT BASE OF STACK
- STAGE 1 OTV IS DESIGNED FOR LARGE MOMENTS & AXIAL LOAD
- STAGE 2 OTV MOMENTS ARE MUCH LOWER, BUT COMMONALITY OF OTV MODULES FORCE OVERDESIGN OF 2ND STAGE OTV BODY SHELL
 - LARGE WEIGHT PENALTY DUE TO 2ND STAGE OTV OVERDESIGN

FBRS SIGNIFICANTLY REDUCES BENDING IN PAYLOAD STACK

- 86% OF FULL LATERAL REACTION POSSIBLE WITH NOMINAL SHROUD SIZING
- **USE OF FBRS MINIMIZES OTV BODY SHELL WEIGHT**
- RECOMMEND INVESTIGATION OF SECOND FBRS TO FURTHER REDUCE OTV **BODY SHELL WEIGHT TO MINIMUM VALUE**
- MINIMUM WEIGHT POSSIBLE IS FOR MAX AXIAL LOADS FOLLOWING SHROUD **JETTISON (NO FBRS POSSIBLE)**

Fx = 3.455 g's (AXIAL) Fy = 0 (LATERAL) Fz = 0 (LATERAL) previously for the partially reusable vehicles. The difference is that after the OTV, with payload, is deboosted from GEO, the entire OTV separates from the payload module and is destroyed on reentry. The payload with its own aerobrake, avionics, and delta V capability performs an aeromaneuver and is recovered either at the Space Station or by the Shuttle. The flight operations for the expendable OTV with aeroassist return payloads are shown in figure 3.6.1. Examining the effect of this approach on the evolutionary path of the vehicle, shown in the figure 3.6-2, it can be seen that a single large stage is sufficient to perform all of the larger missions in the model. The configuration for this concept is shown in figure 3.6-3 and the summary weight statement is given in Table 3.6-1. This vehicle is sized for a usable propellant loading of 79,000 lb. All subsystems included in this vehicle are similar to those of the all-propulsive large stage expendable OTV. The launch configuration, as well as the ASE associated with this concept, are given in figure 3.6-4.

3.7 SB FULLY REUSABLE SYSTEM

Table 3.7-1 shows the difference between ground-based and space-based fully reusable OTV subsystems. Because the space-based vehicle is launched to LEO empty, the support structure does not need to be sized for launch loads. Instead, the structure is sized for loads at aeromaneuver when the tanks are only partially full. Thus, instead of a body shell, external meteoroid/debris shielding must be provided for the OTV. In all of the other vehicle subsystems the components are similar to those for the ground-based vehicles except that on-orbit removal provisions must be added for some of the components. Also, a GN2 auxiliary propulsion system must be added for deployment and retrieval operations at the space station for the space-based OTV. The on-orbit dormancy provisions that were necessary on the small GB fully reusable vehicle are not necessary on the space-based vehicle.

3.7.1 Mission Application

Figure 3.7-1 shows the vehicle evolutionary path of the space-based fully reusable vehicle as applied to the mission model. This evolution is similar to that of the ground-based vehicle. The small stage, sized to do the early delivery missions, has a usable propellant loading of 46,800 lb. The large stage, sized to do the later manned missions, has a usable propellant loading of 70,200 lb.

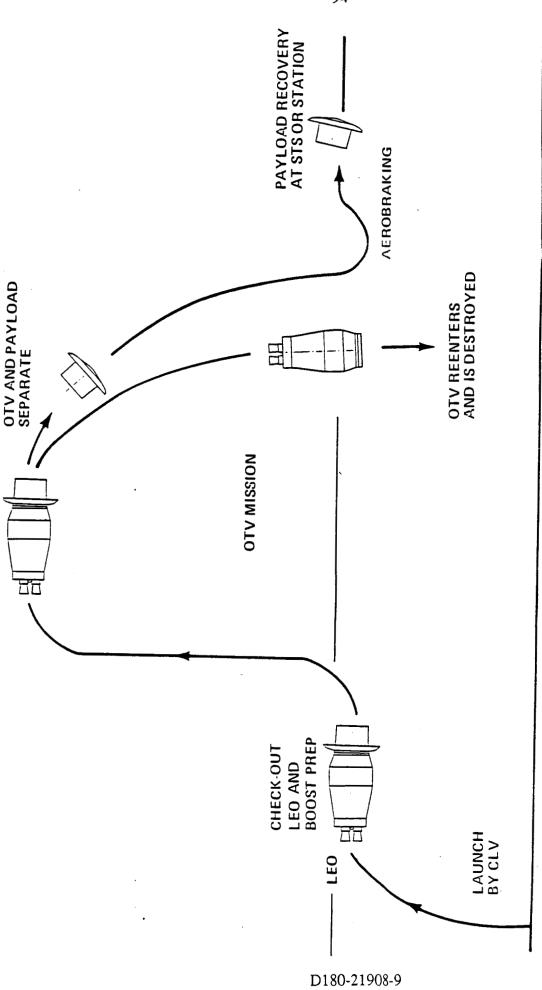


Figure 3.6-1 Expendable OTV Flight Operations Aerobrake Return Payloads

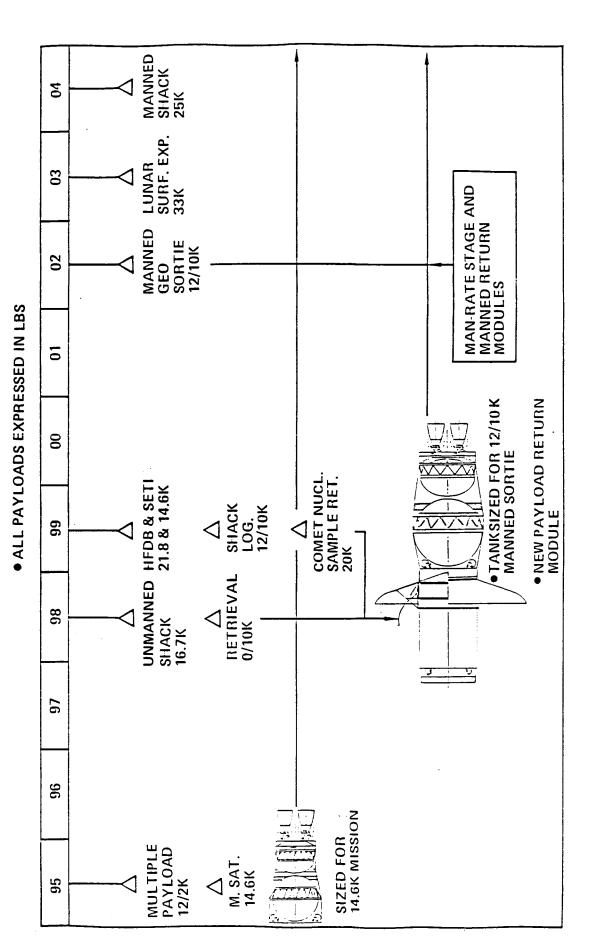
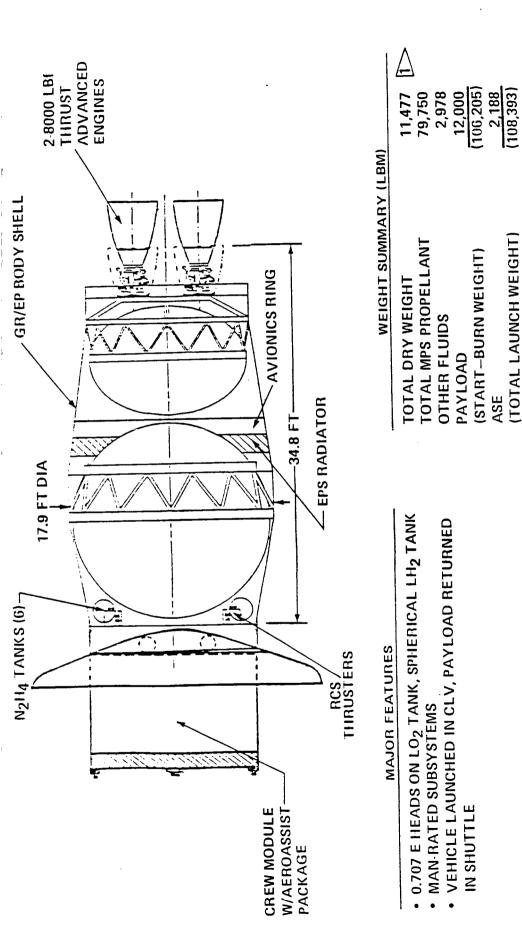


Figure 3.6-2 Expendable OTV Mission Application—Aeroassisted Payload Return—

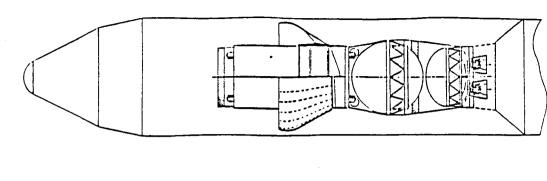


(1) INCLUDES 7488 LB STAGE, 242 LB INTERSTAGE, AND 3747 LB AERO SCAR

Figure 3.6-3 Large GB Expendable OTV (Aeroassisted Payload Return) Configuration

Table 3.6-1 OTV Weight Summary Large GB Expendable – Aeroassist Payload Recovery

	WEIGHT (LBM)	(LBM)
	Cost-Optimum	Man-Rated
STRUCTURES AND MECHANISMS	3437	3437
BODY STRUCTURE	2228	2228
TANKAGE	1162	1162
MET/DEB SHIELDING	47	47
THERMAL PROTECTION AND CONTROL	361	361
MAIN PROPULSION, LESS ENGINES		400
MAIN ENGINES (2-8000 lbf ASE)	512	512
AUXILIARY PROPULSION	241	263
GUIDANCE AND NAVIGATION	55	110
COMMUNICATIONS AND DATA HANDLING	339	422
ELECTRICAL POWER	580	743
WEIGHT GROWTH	885	931
(DRY WEIGHT)	(7049)	(7488)
RESIDUALS	807	807
(EOM WEIGHT, EXCLUDING RESERVES)	(1856)	(8295)
EPS REACTANTS	08	80
PRESSURANTS	8	80
RCS USABLE PROPELLANTS (INCLUDING FPR)	1050	1050
MPS USABLE PROPELLANTS (INCLUDING FPR)	000'62	79,000
(GROSS WEIGHT)	(87,994)	(88,433)



100

PAYLOAD SUPPORT EQUIP.

• CABLING, MISC.

CLV LAUNCII LARGE STAGE

■ COMMON GOV'T FURN. EQUIP.

FITTING ALLOWANCE

WEIGHT (LBM)

SINGLE STAGE CLV LAUNCH (SHOWN WITH 12K LOGISTICS P/L)

WEIGHTS ARE EQUIVALENT WEIGHTS TO ORBIT

2188

2088

CONTRACTOR EQUIP

(TOTAL)

[→ ASSUME INCLUDED IN LAUNCH VEHICLE WEIGHT

Figure 3.64 GB Expendable Stage Launch ASE

2088

100

CONTRACTOR EQUIP

PAYLOAD KITS

ATTACH FTGS.

● STAGE SUPPORT EQUIP

ATTACH FTGS.

• MISC. GFE

Table 3.7-1 GB FRS and SB FRS Subsystem Comparison

ITEM	GB FULLY REUSABLE OTV	SB FULLY REUSABLE OTV
• BODY STRUCTURES	GR/EP BODY SHELL DESIGNED FOR LAUNCH LOADS	GR/EP STRUTS DESIGNED FOR AERO- MANEUVER LOADS
• TANKAGE	STRUT-SUPPORTED 2219-T87 ALUM.' DESIGNED FOR 45 MISSION LIFE	SAME
• MET/DEB PROTECTION	PROVIDED BY GR/EP BODY SHELL/MLI 9995 PROB. ON NO. TANK IMPACT	PROVIDED BY.016 IN ALUM BARRIERAND MLI –.999 PROB. OF NO. TANK IMPACT
• THERMAL PROTECTION & CONTROL	FSI ON BODY FOR HI-TEMP BALLUTE; MLI ON TANKAGE; FUEL CELL RADIATORS	SAME
• MAIN PROPULSION	2-6000 LBf ADVANCED ENGINES	SAME, BUT WITH ON-ORBIT REMOVAL PROVISIONS
• AUXILIARY PROPULSION	N ₂ H ₄ EXTERNAL PRESS. DIAPHRAGM TANKS, 25-LBf THRUSTERS	SAME, WITH SPACE MAINT OF THRUSTERS; ALSO GN ₂ SYSTEM FOR RETRIEVAL OPS.
• GUIDANCE & NAVIGATION	IMU, STAR TRACKERS, GPS	SAME, WITH ON-ORBIT MAINTENANCE OF IMU, GPS
• COMMUNICATIONS/DATA	TDRS TRANSPONDER, INTEGRATED DMS, LOADING & HEALTH INSTRUMENTAITON	SAME, WITH ON-ORBIT MAINTENANCE PROVISIONS OF TRANSPONDER' DMU's
• ELECTRICAL POWER	2.0 KW NOM O ₂ /H ₂ FUEL CELLS SOLAR ARRAY FOR ON-ORBIT DORMANCY	SAME, WITH ON-ORBIT MAINTENANCE, NO DORMANCY PROVISIONS
• AEROASSIST	1500° B/W TEMP. EXPENDABLE BALLUTE	SAME, BUT WITH ON-ORBIT ASSEMBLY PROVISIONS

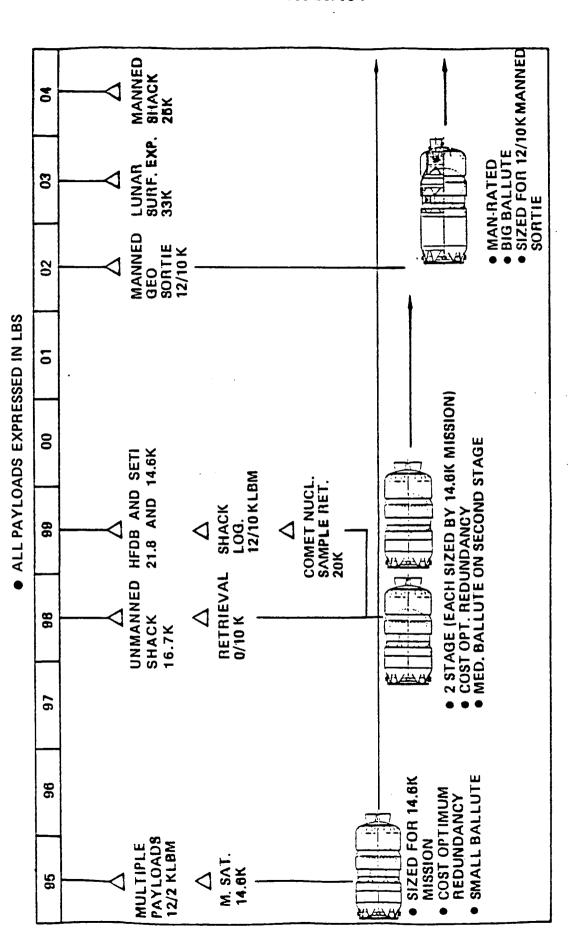


Figure 3.7-1 FRS OTV Mission Application

3.7.2 Operational Description

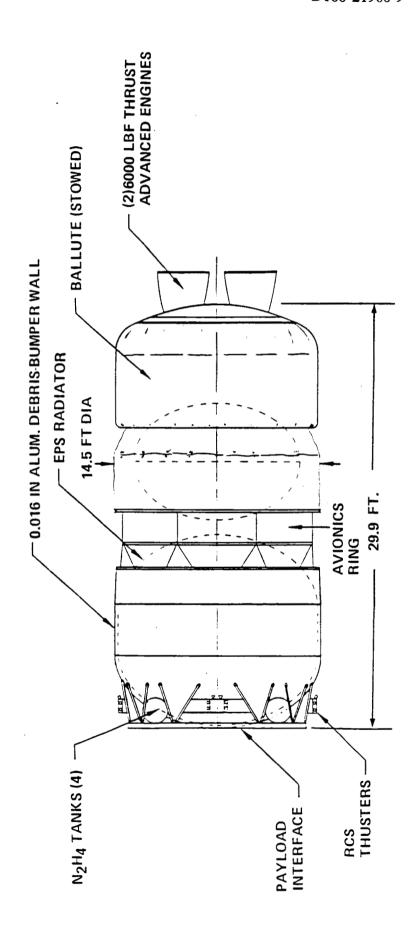
Both the small and large space-based vehicles are launched empty and are kept in hangars at the Space Station. In all mission types, the propellants and payloads are launched to orbit in the CLV, the OTV is refueled and mated to the payload on-orbit, and the mission is performed. Upon return, after an aerobrake maneuver, the stage and payload are recovered at the station and the OTV is refurbished for its next mission. These operations are shown figure 3.7-2.

3.7.3 Configuration Description

The configurations for the small and large space-based OTV's are given in figure 3.7-3 and 3.7-4. Weight summaries for these stages are given in Tables 3.7-2 and 3.7-3. Spacecraft structure consists primarily of 2219-T87 aluminum propellant tanks supported by graphite/epoxy struts. Meteoroid/debris protection is provided by a 0.016 in. aluminum bumper shield surrounding the entire exposed tank area and MLI insulation around the tanks. Main propulsion thrust is provided by two advanced expander-cycle engines, each having a vacuum thrust of 6000 lbf. These engines provide thrust for all orbit transfer maneuvers and have provisions to be removed for on-orbit replacement, provided by structural and plumbing disconnect plates at the engine interface. Auxiliary propulsion is provided by a hydrazine system pressurized by nitrogen gas supplied from separate bottles. Space maintenance of the RCS is also provided for the thruster modules. Electrical power for the mission is provided by 02/H2 fuel cells operating from supercritical 02/H2 storage bottles. Active thermal control is provided for these Other thermal control includes MLI on the main propellant tanks for propellant boiloff control and flexible reusable surface insulation (FRSI) on the vehicle exterior for thermal protection during the aeromaneuver.

For the aeromaneuver, high backwall-temperature ballutes are used. A 37.5 ft diameter ballute is needed to perform the aeromaneuver for small payload delivery missions. Ballute size is determined by a BAC-established criterion to maintain wake impingement heating on the empty payload rack that is returned on some multimanifest missions to below 0.5 BTU/ft² - sec. The larger return payload missions, such as the 12k-lb logistics payload, require a 58.0 ft diameter ballute on the second stage of the two stage system. A 63.0 ft diameter ballute is needed for the large single stage system. These ballute sizes are determined by aerostability criteria but are also sufficient to protect the payload from wake impingement during the aeromaneuver.

Figure 3.7-2 FRS-Flight Operations Space Based



-37.5 FT DIA FOR 2K PAYLOAD RACK RETURN

-58.0 FT FOR 10K LOGISTICS P/L RETURN

COST-OP LIMUM SUBSYSTEMS

BALLUTE AEROASSIST DEVICE EXPENDABLE

BUMPER, MLI BACKWALL

0.707 E HEADS ON LH₂, LO₂ TANKS METEOROID/DEBRIS SHIELDING OF ALUMINUM

MAJOR FEATURES

7,487 47,282 1,004 14,600 (70,373)

Figure 3.7-3 Small SB Fully Reusable OTV Configuration

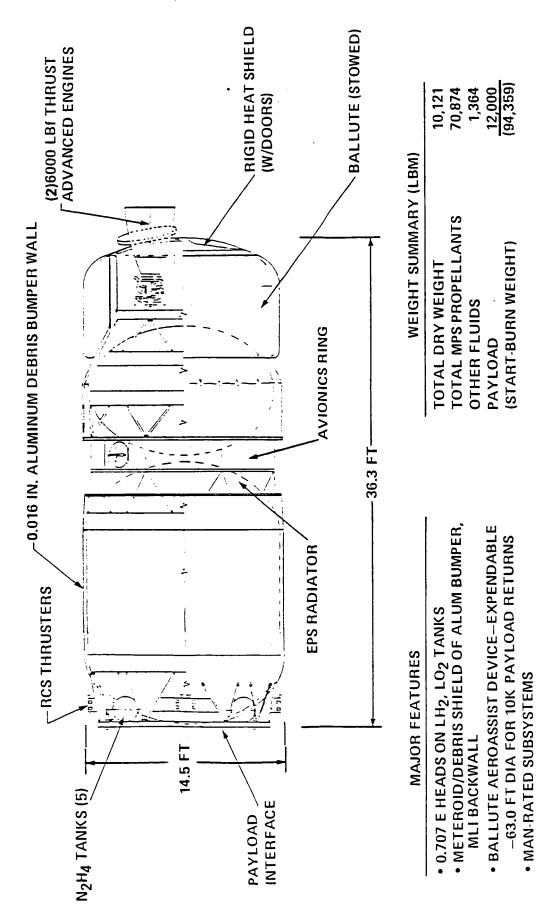


Figure 3.74 Large SB Fully Reusable OTV Configuration

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58.0 FT DIA BALLUTE	2193	1058	829	276	2352	1504	848	496	208	428	407	134	422	544	1079	(8263)	260	-2085	(2038)	+2085	80	224	200	46,800	(26,927)
37.5 FT DIA BALLUTE	2193	1058	829	276	1416	938	478	496	208	428	407	134	422	544	. 939	(7487)	290	-1045	(7002)	+1045	- 80	176	670	46,800	(55,773)
	STRUCTURES AND MECHANISMS	BODY STRUCTURE	TANKAGE	MET/DEB SHIELDING	AEROASSIST DEVICE	STRUCTURE	THERMAL PROTECTION	THERMAL PROTECTION AND CONTROL	MAIN PROPULSION, LESS ENGINES	MAIN ENGINES (2-6000 lbf ASE)	AUXILIARY PROPULSION	GUIDANCE AND NAVIGATION	COMMUNICATIONS AND DATA HANDLING	ELECTRICAL POWER	WEIGHT GROWTH	(DRY WEIGHT)	RESIDUALS	JETTISONABLE ITEMS, INCLUDING GROWTH	(EOM WEIGHT, EXCLUDING RESERVES)	JETTISONABLE ITEMS, INCLUDING GROWTH	EPS REACTANTS	PRESSURANTS (INCL GAS FOR DEPLOY/RET.)	RCS USABLE PROPELLANTS (INCLUDING FPR)	MPS USABLE PROPELLANTS (INCLUDING FPR)	(GROSS WEIGHT)

	WEIGHT (LBM)
STRUCTURES AND MECHANISMS	2678
	1107
TANKAGE	1187
MET/DEB SHIELDING	384
AEROASSIST DEVICE (63.0 ft Dia.)	2667
STRUCTURE	1703
THERMAL PROTECTION	964
THERMAL PROTECTION AND CONTROL	621
MAIN PROPULSION, LESS ENGINES	286
MAIN ENGINES (2-6000 lbf ASE)	428
AUXILIARY PROPULSION	463
GUIDANCE AND NAVIGATION	154
COMMUNICATIONS AND DATA HANDLING	521
ELECTRICAL POWER	730
WEIGHT GROWTH	1273
(DRY WEIGHT)	(10,121)
RESIDUALS	764
JETTISONABLE ITEMS, INCLUDING GROWTH	.2389
(EOM WEIGHT, EXCLUDING RESERVES)	(8496)
JETTISONABLE ITEMS, INCLUDING GROWTH	+2389
EPS REACTANTS	80
PRESSURANTS (INCL. GAS FOR DEPLOY/RET.)	244
RCS USABLE PROPELLANTS (INCLUDING FPR)	950
MPS USABLE PROPELLANTS (INCLUDING FPR)	70,200
(GROSS WEIGHT)	(82,359)

3.8 SB PARTIALLY REUSABLE OTV

Table 3.8-1 shows the major subsystem differences between the ground-based and space-based partially reusable vehicles. The tanksets are nearly identical since both are launched from the ground fully loaded. The P/A module is the only part of this vehicle that is space-based and therefore all of the P/A module subsystems have space maintenance provisions. Also, a GN2 auxiliary propulsion systems is provided for deployment and retrieval at the space station. No on-orbit dormancy provisions are required on the space-based version because it goes directly to the Space Station following its mission.

3.8.1 Mission Application

Figure 3.8-1 shows the evolutionary path of the space-based partially reusable vehicle as applied to the mission model. As before, several options are available for this vehicle evolution. The selected approach, as shown in the figure, consists of two tanksets for the two mission types, i.e., the small 14.6k-lb delivery and the 12k/10k-lb roundtrip. The smaller stage is sized for a usable propellant loading of 50,400 lb while the larger tankset is sized for a usable propellant loading of 90,800 lb. The P/A module is the same size for all vehicles and is manrated as the manned missions occur.

3.8.2 Operational Description

For the space-based version of the partially reusable vehicle, the CLV launches the tanksets, aerobrakes and payload to the Station where vehicle assembly occurs. Return from a GEO payload delivery mission initially involves the vehicle performing a deorbit burn targeted for entry into the earth's atmosphere and burn-up. The P/A module separates from the tankset shortly after the deorbit burn and makes a corrective burn using its RCS so it is targeted for an aeromaneuver at LEO. The separation is done so that the P/A module will reenter and perform its aeromaneuver at least six minutes before the tankset reenters and is destroyed. Once the aeromaneuver is performed, the aerobrake is jettisoned and the P/A module performs its correction and circularization burns using RCS to put itself into the proper LEO orbit to return to the station.

Payload return (roundtrip) missions differ in that, after the deorbit burn from GEO, the vehicle first targets and releases the return payload with its own aeroassist system for an aeromaneuver; then the tankset is targeted and released; and then the P/A module is targeted for its aeromaneuver. Again, a minimum of six minutes is allowed for separation of the vehicles on reentry. In this case, the return payload and the P/A

Table 3.8-1 GB PRS and SB PRS Subsystem Comparison

ITEM	GB PARTIALLY REUSABLE OTV	SB PARTIALLY REUSABLE OTV
• BODY STRUCTURES	GR/EP BODY SHELL DESIGNED FOR LAUNCH LOADS — TANK MODULE	SAME
• TANKAGE	STRUT-SUPPORTED 2219-T87 ALUM, DESIGNED FOR 1 MISSION LIFE	SAME
• MET/DEB PROTECTION	PROVIDED BY BODY SHELL/MLI .9995 PROB. OF NO TANK IMPACT	SAME
• THERMAL CONTROL	MLI ON TANKAGE, PLUMBING	SAME
• MAIN PROPULSION	2-7000 LBf ADVANCED ENGINES ON P/A MODULE	SAME, BUT WITH ON-ORBIT REMOVAL PROVISIONS
• AUXILARY PROPULSION	N ₂ H ₄ EXTERNAL PRESS. DIAPHRAPM TÂNK ON P/A MOD.; 100 LBf THRUSTERS FOR △V	SAME, WITH THRUSTER REMOVAL PROV, & GN ₂ SYSTEM FOR RETRIEVAL
• GUIDANCE AND NAVIGATION	IMU, STAR TRACKER, GPS ON P/A MODULE	SAME, WITH SPACE MAINTENANCE PROV, FOR IMU, GPS
• COMMUNICATIONS/DATA	TDRS XPONDER, INTEGRATED DMS, HEALTH MONITORING ON P/A MOD.	SAME, WITH SPACE MAINTENANCE PROV, FOR XPONDER, DMU
• ELECTRICAL POWER	2.0 KW NOM O ₂ /H ₂ FUEL CELLS, SOLAR ARRAYS FOR ON-ORBIT DORMANCY	SAME, WITH SPACE MAINTENANCE PROV; NO ON-ORBIT DORMANCY PROV.
• AEROASSIST	550° B/W TEMP. RIGID LIFTING BRAKE WITH ABLATOR TPS ON P/A MODULE	SAME, BUT LAUNCHED WITH TANKSET

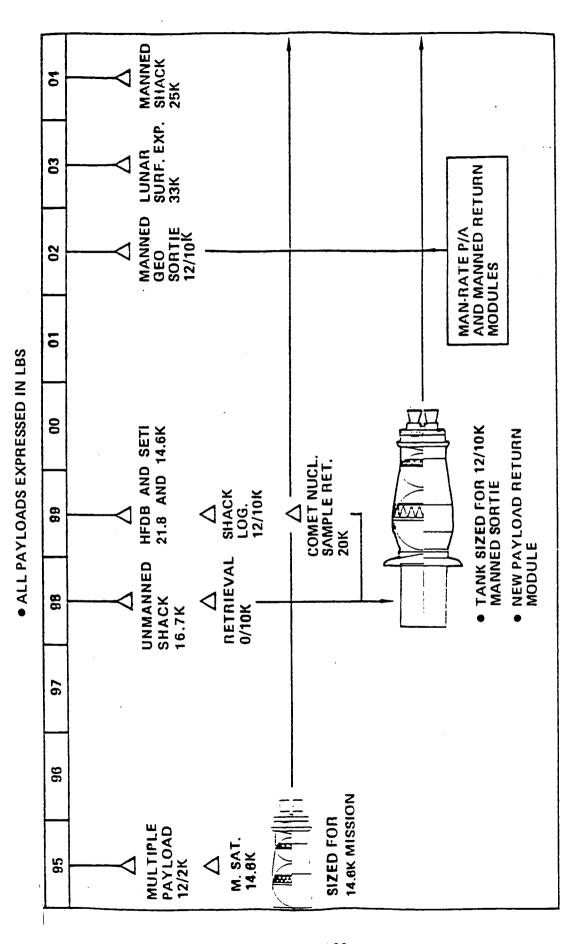


Figure 3.8-1 PRS OTV Mission Application

module return to LEO to be retrieved at the Space Station. These operations are shown in figure 3.8-2.

3.8.3 Configuration Description

The configurations for the small and large space-based partially reusable OTV's are shown in figures 3.8-3 and 3.8-4. Associated weight statements are given in Tables 3.8-2 and 3.8-3. The small and large tanksets have identical structure to the ground-based versions, with a GR/EP body shell enclosing strut-supported aluminum tanks.

The P/A module contains the main propulsion, auxiliary propulsion, electrical power, guidance and navigation, and data handling. Main propulsion thrust is provided by two advanced expander cycle engines having a vacuum thrust of 7000 lbf each. These engines are sized by applying a 0.12 thrust-to-weight factor to the large manned servicing mission, for which the large tankset is sized. Space maintenance provisions for the main engines are included as structural and plumbing disconnects. The auxiliary propulsion system includes a hydrazine system, like that on the ground-based PRS, and a gaseous nitrogen thruster system for close proximity operations near the Space Station. The hydrazine system has four 100 lbf thrusters on the aft end, in addition to the 25 lb thrusters, used to perform the necessary post-aero correction and circularization delta V's. The nitrogen system has small 5 lbf thrusters to provide small delta V capability with low contamination. Provisions for space maintenance of the thruster modules are also included for the RCS systems.

Like the GB PRS, the SB PRS power is provided by 02/H2 fuel cells and the same avionics subsystems are used. On the space-based P/A module, space maintenance provisions are included for some of these subsystems. Thermal control consists of MLI on the propellant tanks, and FRSI around the engine cavity to protect the sensitive avionics and structure from radiation heating from the main engines.

The space-based P/A module, like the ground-based one, performs an aeromaneuver by means of a rigid symmetric lifting brake. In this case, though, the brake is attached to the P/A module with electromechanical latch/release mechanisms for ease of onorbit assembly at the Space Station. The brake is expendable and is covered with an ablative TPS.

The payload return concepts for the space-based partially reusable vehicle are very similar to those for the ground-based vehicle. As with the P/A module, extra GN2 propulsion systems must be provided on the SB return payload module for station retrieval operations.

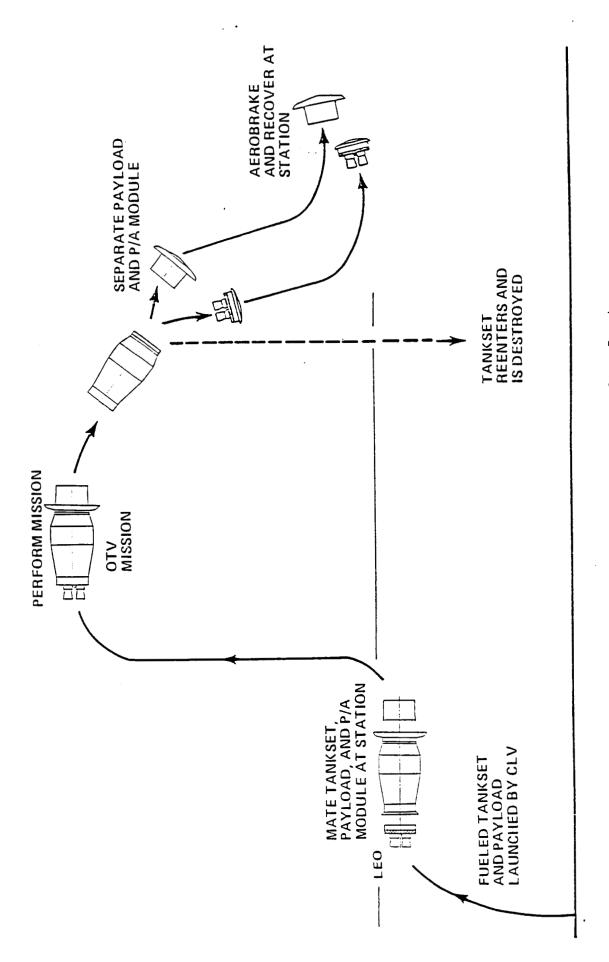


Figure 3.8-2 PRS Flight Operations-Space Based

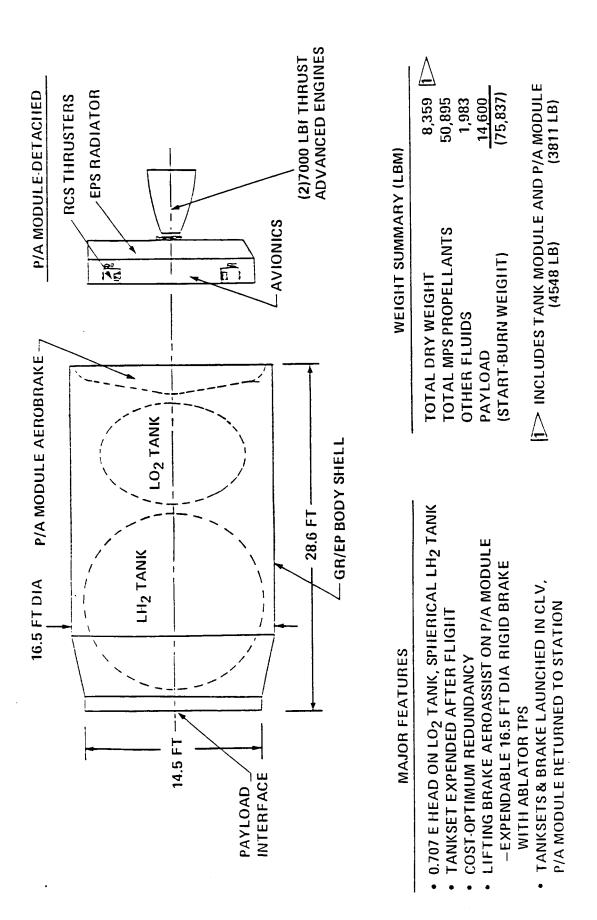
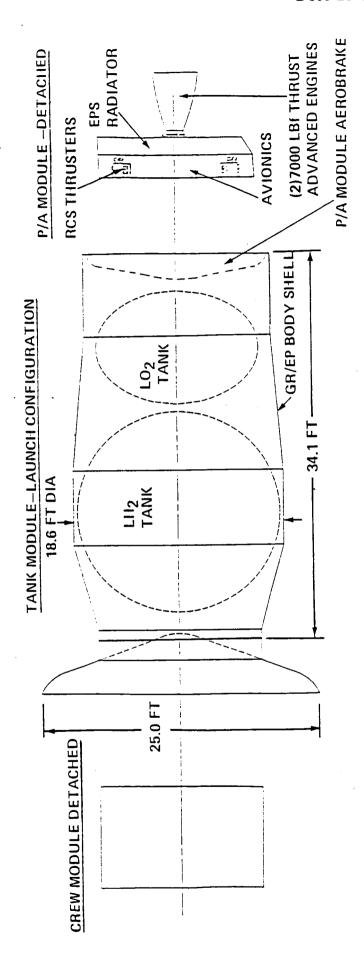


Figure 3.8-3 Small SB Partially Reusable OTV Configuration



İ	14,688 [1_> 91,618	4,786 12,000	(123,092)	DULE, AND LB)	SCAR
WEIGHT SUMMARY (LBM)	TOTAL DRY WEIGHT TOTAL MPS PROPELLANTS	OTHER FLUIDS PAYLOAD	(START-BURN WEIGHT)	TANK MODULE, P/A MODULE, AND (6470 LB) (4229 LB)	PAYLOAD AEROASSIST SCAR (3989 LB)

• 0.707 E HEAD ON LO₂ TANK, SPHERICAL LII₂ TANK • TANKSET EXPENDED AFTER EACH FLIGHT

MAJOR FEATURES

• TANKSET AND BRAKES LAUNCHED IN CLV, P/A MODULE RETURNED TO STATION

-EXPENDABLE RIGID BRAKE

· LIFTING BRAKE AEROASSIST

MAN-RATED REDUNDACY

Figure 3.8-4 Large SB Partially Reusable OTV Configuration

Table 3.8-2 OTV Weight Summary Small SB Partially Reusable OTV

EPS REACTANTS PRESSURANTS (INCLUDING 233 LB GN ₂ FOR DEPLOYMENT)

WEIGHT (LBM)

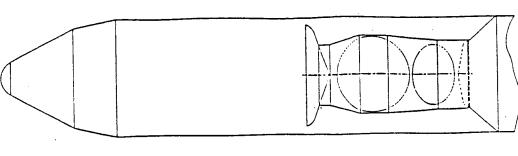
P/A MODULE	639	639					0	100	170	407	922	<u> </u>	432	707	1492	(4,229)	123	14 25 21	(4,352)	987/+		. 240	2,080	008'06	(104,840)
TANK MODULE	3,870	2,417	1,406	4/	040	909	28/	31/	4/2	0	0	0	65	96	844	(6,4/0)	818	.973	(918,9)						
	STRUCTURES AND MECHANISMS	BODY STRUCTURE	TANKAGE		AEROASSIST DEVICE (16.5 FT. DIA.)	STRUCTURE	THERMAL PROTECTION	THERMAL PROTECTION AND CONTROL	MAIN PROPULSION, LESS ENGINES	MAIN ENGINES (2 – 7000 LBF ASE)	AUXILIARY PROPULSION	GUIDANCE AND NAVIGATION	COMMUNICATIONS AND DATA HANDLING	ELECTRICAL POWER	WEIGHT GROWTH	(DRY WEIGHT)	RESIDUALS (INCLUDING RCS PRESSURANTS)	JETTISONABLE ITEMS, INCLUDING GROWTH	(EOM WEIGHT, EXCLUDING RESERVES)	JETTISONABLE ITEMS, INCLUDING GROWTH	EPS REACTANTS	PRESSURANTS (INCLUDING 233 LB GN ₂ FOR DEPLOYMENT)	RCS USABLE PROPELLANTS (INCLUDING FPR)	MPS USABLE PROPELLANTS (INCLUDING FPR)	(GROSS WEIGHT)

3.8.4 Launch Concept

The launch arrangement of the tankset and P/A module aerobrake associated with a SB PRS is shown in figure 3.8-5 along with ASE weights.

1947

1747



·	·

100

100

I

CONTRACTOR EQUIP

PAYLOAD KITS

ATTACH FTGS.

STAGE SUPPORT EQUIP

• ATTACH FTGS.

MISC. GFE

100

100

PAYLOAD SUPPORT EQUIP.

CABLING, MISC.

CLV LAUNCH LARGE STAGE

CLV LAUNCH SMALL STAGE

COMMON GOV'T FURN. EQUIP.

FITTING ALLOWANCE

WEIGHT (LBM)

LARGE STAGE CLV LAUNCH (SHOWN WITH 25.0 FT AEROBRAKE)

WEIGHTS ARE EQUIVALENT WEIGHTS TO ORBIT

2047

1847

1947

1747

● CONTRACTOR EQUIP

(TOTAL)

Figure 3.8-5 SB PRS Stage Launch ASE

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4.0 AEROASSIST ANALYSIS

This section describes the aeroassist guidance and aerothermal analysis unique to the partially reusable OTV concept. Aeroassist data associated with the ballute braked OTV, is the same as defined in the Phase I documentation of Volume II, Book 2, and Volume II, Books 3.

4.1 Aeroassist Guidance

The new PRS vehicle has a return strategy different from previous aeroassist vehicles and, because of the higher ballistic coefficients, has potentially different concerns for aeroassist guidance.

4.1.1 PRS Vehicle

The partially reusable stage (PRS) consists of three elements as shown in figure 4.1-1. The main propulsion and avionics for the vehicle are part of the P/A module along with an aerobrake used for return to LEO. The payload (crew module or logistics module) has its own brake. The atmospheric entry parameters for the aerobraking module options are shown in figure 4.1-2. The final element is the tank set which has no aerobrake and is targeted to burn up in the atmosphere after mission completion.

4.1.2 PRS Returns

From GEO deorbit to LEO circularization, the PRS mission sequence is the same for both ground and space basing. However, there are two different return strategies: one for unmanned delivery missions and another for manned servicing missions.

For the unmanned delivery missions, the payload remains at GEO and only the tank set and P/A module returns. The return sequence for this mission is for a deorbit burn of 6050 fps using the MPS. This places the combination in a 45 X 19323 nm orbit. The P/A module separates from the tank set and immediately does a +198 fps ACS burn to place the P/A module into a 45 X 19329 nm orbit with a flight angle of -2.185 deg. On this orbit, the P/A module will enter the atmosphere (400,000 ft) in 307 minutes. The tank set will enter the atmosphere in 313 minutes after separation and burn up. The P/A module will execute an aeromaneuver and be recovered.

The sequence for the manned servicing missions consists of a GEO deorbit burn using the MPS. This 6050 fps burn places the vehicle in a 45×19232 nm orbit. The crew module separates from the P/A module and tank set and enters the atmosphere at 400,000 ft in 313 minutes. After separation from the crew module, another MPS

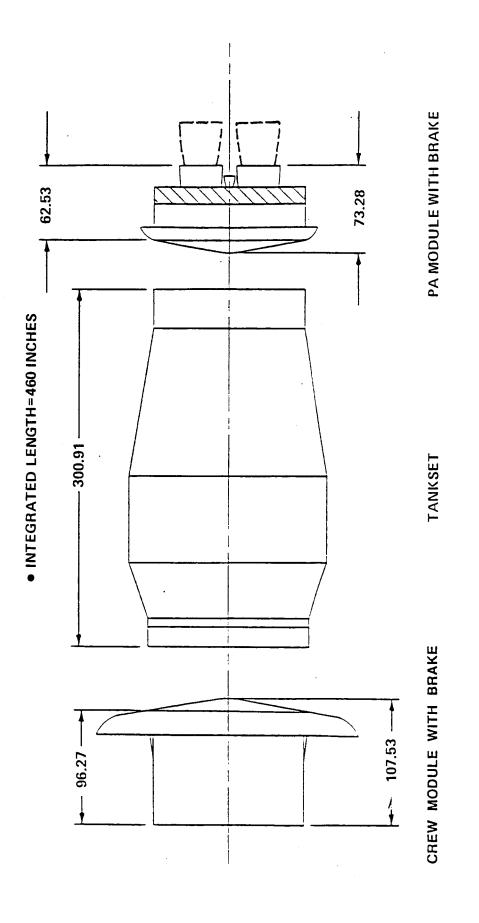


Figure 4.1-1 Partially Reusable Stage Elements 10K Manned Cab Return

DIMENSIONS IN INCHES

BASING MODE	REENTRY ELEMENT	REENTRY WT (LBM)	BRAKE DIA. (FT)	BALLISTIC COEFFICIENT (LBM/FT ²)
	• P/A MODULE, COST OPT.	5,610	16	19.9
EITHER	• 10K LB CREW MODULE	15,900	25	23.1
	• 10K LB LOG.	16,600	38	10.5
GROUND	• P/A MODULE, MAN.BATED	6,346	16	22.5
SPACE	• P/A MODULE, MAN RATED	980′9	16	21.6

 \bullet CD = 1.4

● 100 ANGLE -OF-ATTACK

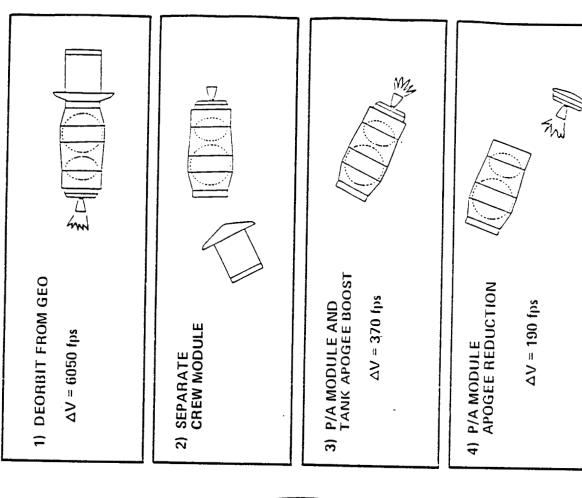
Figure 4.1-2 PRS Reentry Parameters

maneuver of +371 fps places the P/A module and tank set into a 45 x 19344 nm orbit with a +4.08 deg flight path angle. The P/A module then separates from the tank and does a -190 fps ACS burn. This places the P/A module into a 45 x 19328 nm orbit with a +1.99 deg flight path angle. The P/A module will reach the atmosphere in 318 minutes, followed by the tank set at 324 minutes. This sequence is illustrated in figure 4.1-3.

4.1.3 Guidance Simulation

During this phase of the contract, the primary emphasis on aeroassist guidance was to assess the effects of vehicle roll dynamics, low L/D limits, and increased ballistic coefficient on the guidance error during the aeromaneuver. Modifications to the computer simulation, OPTIC, were required to model the effects of inertia and finite roll rates on the guidance errors. The structure of the modified Gamma Guidance algorithm makes it possible to anticipate the finite time required to execute a guidance command. This minimizes the impact of the vehicle dynamics on the guidance errors. The choice of a command philosophy has a much larger impact on the propulsive delta-v necessary to circularize in the recovery or phasing orbit, than does the finite execution time.

Earlier guidance analysis of low L/D aeroassist vehicles ignored the effects of vehicle roll dynamics and assumed instantaneous response to guidance commands. In order to satisfy final orbit constraints of radius-of-apogee and both inclination and RAAN, it is necessary to command bank angle reversals. Of course, instantaneous response is increasingly unrealistic for large roll reversals. To assess the effect of finite response time, the OPTIC guidance simulation was modified to include angular acceleration and angular rate limits on the response to a commanded bank angle reversal or change in bank angle. Because the Gamma Guidance algorithm projects (integrates) the anticipated atmospheric trajectory forward to atmospheric exit using the present command profile, the guidance algorithm can anticipate the effects of the finite response time and base the update command on the anticipated delay in the execution of a change in the bank angle or bank angle reversals. Figure 4.1-4 is a block diagram of the guidance algorithm. The algorithm was modified to include vehicle roll dynamics in the trajectory prediction block. Modifications to the OPTIC simulation are indicated on the structure diagram in figure 4.1-5. These include the modifications to the algorithm, plus the modifications to the vehicle flight simulation block.



6 MINUTE TIME
DIFFERENCE IN
REENTRY POINT

Figure 4.1-3 PRS Manned Return Profile

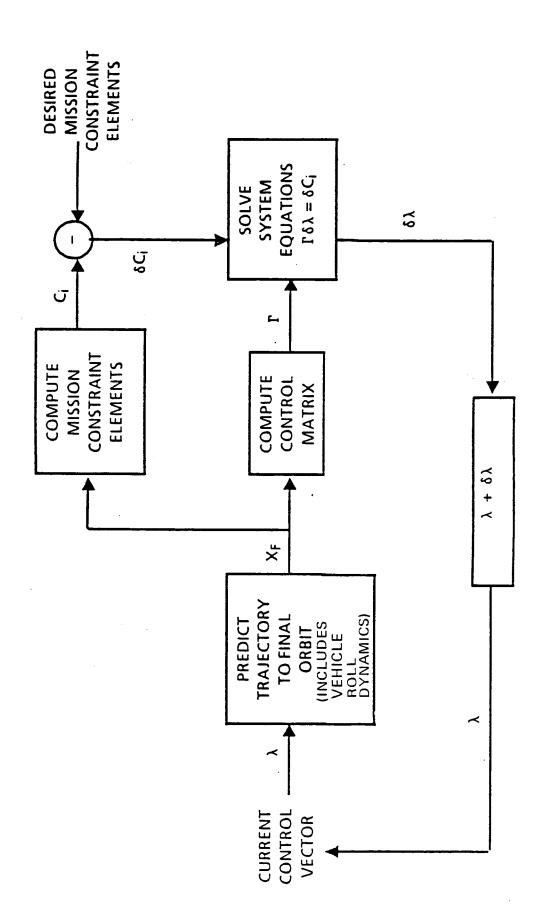


Figure 4.14 Adaptive Guidance Algorithm

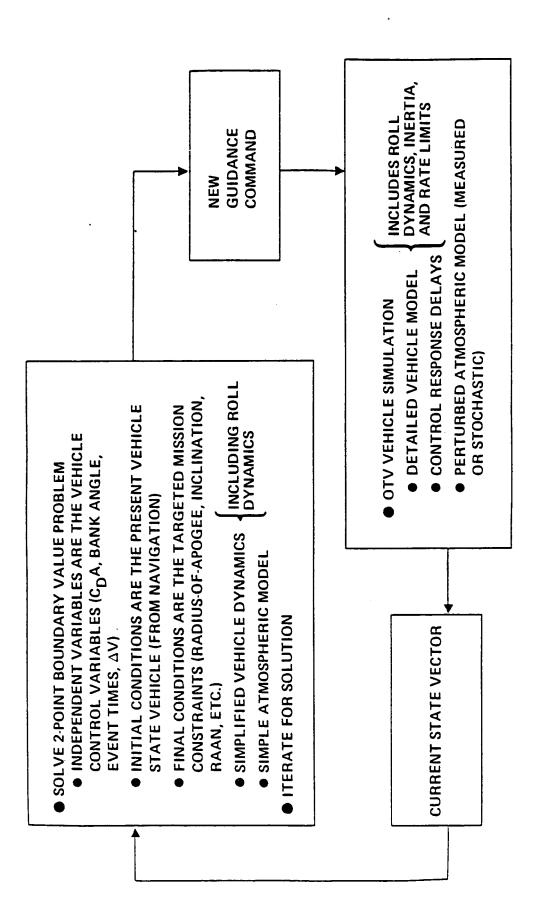


Figure 4.1-5 Guidance Simulation Structure

4.1.4 Guidance Response

The most significant impact of finite bank angle response is in the choice of control variables or the command profile. In the case of instantaneous response, it is only necessary to have the capability to execute two or three bank angle reversals in order to achieve the desired exit plane with the correct radius-of-apogee, inclination, and RAAN. However, when finite response is imposed, the choice of direction of roll becomes important. In executing a reversal, it is possible to roll either through the lift-up or the lift-down positions with different results for the guidance response.

The effect of the choice of roll direction was investigated on nominal trajectories for two vehicles. The two low L/D vehicles were a P/A module and a logistics module with parameters given in figure 4.1-6. The P/A module had a ballistic coefficient of 21.1 lbm/ft**2 with a ballistic coefficient of 10.2 lbm/ft**2 for the logistics module. A return from GEO was assumed for initial entry conditions with the aeromaneuver targeted for an exit trajectory of 150 nm apogee, inclination of 28.5 deg, and RAAN of 0 deg. The entry trajectory was also at an inclination of 28.5 deg and 0 deg RAAN. These conditions did not take advantage of any plane change capability during the aeromaneuver, but required the guidance to remove any plane change occurring during the aeropass. The guidance algorithm actually targeted both inclination and RAAN. With the Modified Gamma Guidance algorithm, it is possible to target plane change (or wedge) angle. However, inclination and RAAN were used because plane change angle does not determine a unique final orbit plane.

Figures 4.1-7, -8, and -9 show results obtained for the two vehicles using the bank angle reversal option which rolls through the lift-up position. The delta-v to insert in the targeted circular orbit was 369.3 ft/sec for the logistics module and 377.7 ft/sec for the P/A module. This shows that the effect of ballistic coefficient on the propulsive delta-v requirements for the post-aeromaneuvers is small. However, the depth of penetration into the atmosphere (figure 4.1-7) is significantly different for the two vehicles. When more is known about the statistical properties of the atmospheric density variation with altitude, the depth of penetration may be a factor to consider in design of the vehicle. A factor of definite concern, however, is the maximum heating rate as shown in figure 4.1-9. The higher ballistic coefficient vehicle increases the maximum heating rate by a factor of almost 1.4.

Similar results are shown in figures 4.1-10, -11, and -12 for the vehicles using the lift-down bank angle reversal option. The delta-v to insert into the targeted orbit was 211.2 ft/sec for the logistics module and 216.5 ft/sec for the P/A module. The values of the insertion delta-velocities for the two vehicles using the lift-up or lift-down guidance

BALLISTIC COEFFICIENT (LBM/FT ²)	10.2	. 21.1
REFERENCE AREA (FT ²)	1134	201
ר/ם	0.117	0.117
WEIGHT (LBM)	16,600	980'9
VEHICLE	10K LOGISTICS MODULE	P/A MODULE

Figure 4.1-6 Vehicle Parameters

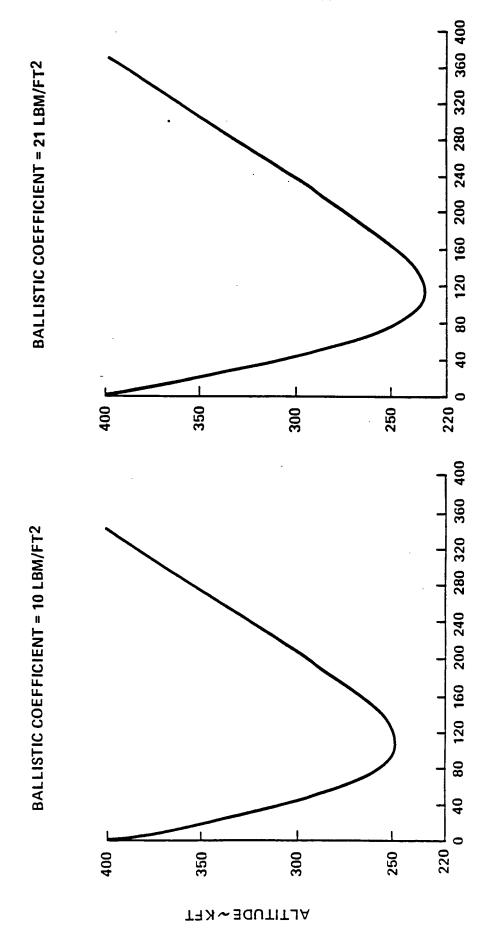


Figure 4.1-7 Effect of Ballistic Coefficient on Atmosphere Penetration

TIME ~SECONDS

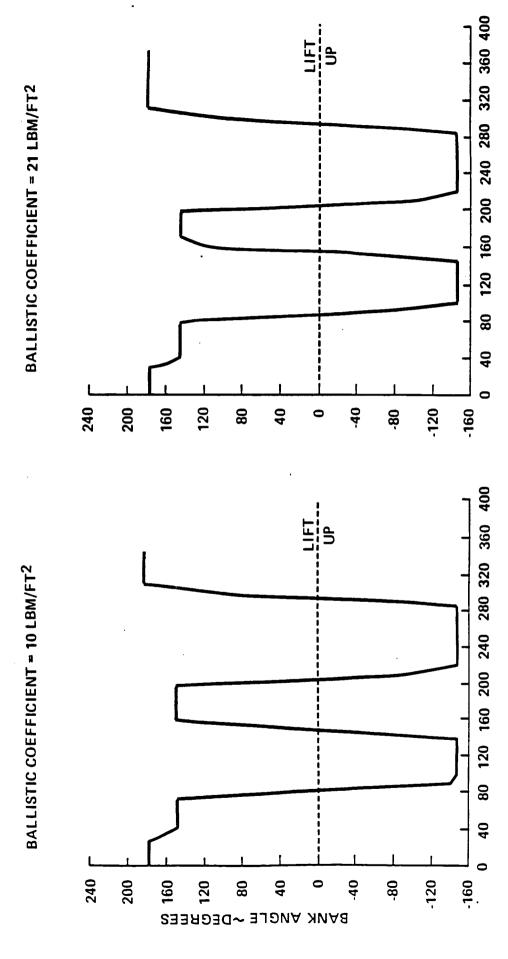
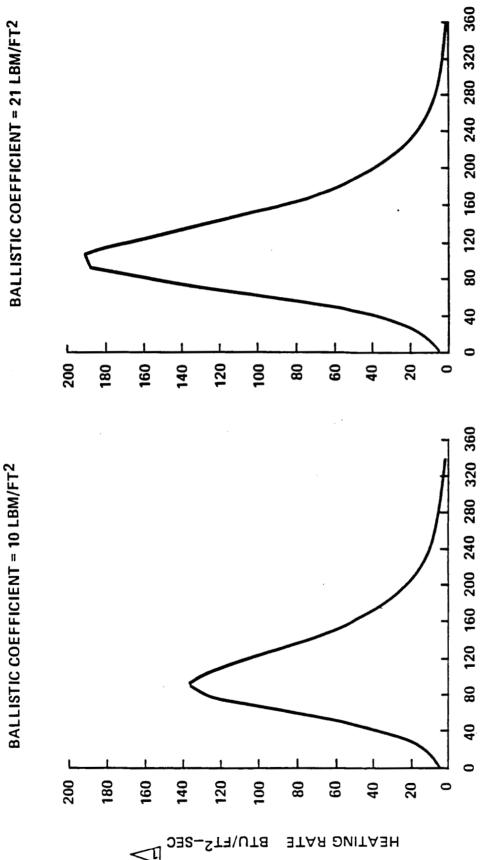


Figure 4.1-8 Effect of Ballistic Coefficient on OTV Bank Angle

TIME~SECONDS



1 AT STAGNATION POINT OF A 1 FT RADIUS HEMISPHERE

TIME~SECONDS

Figure 4.1-9 Effect of Ballistic Coefficient on Heating Rate



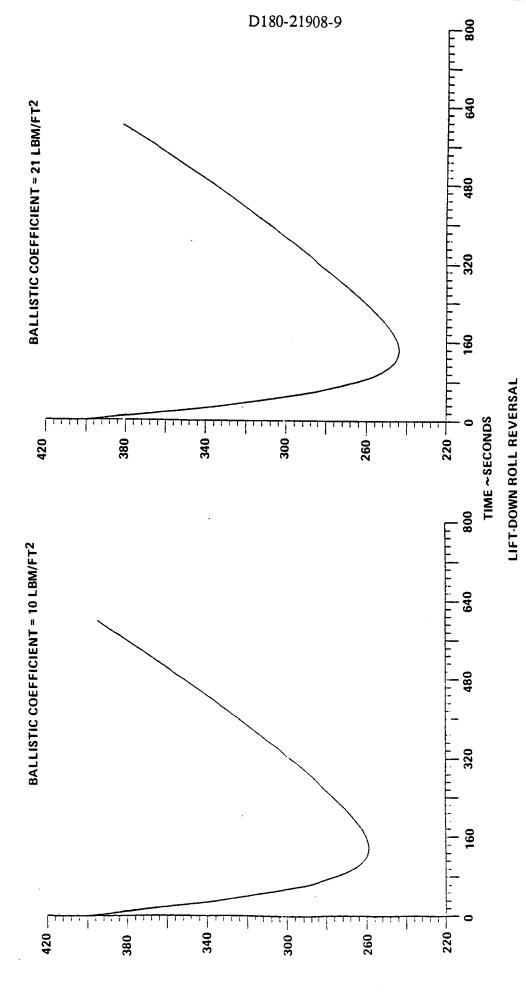


Figure 4.1-10 Effect of Ballistic Coefficient Atmosphere Penetration

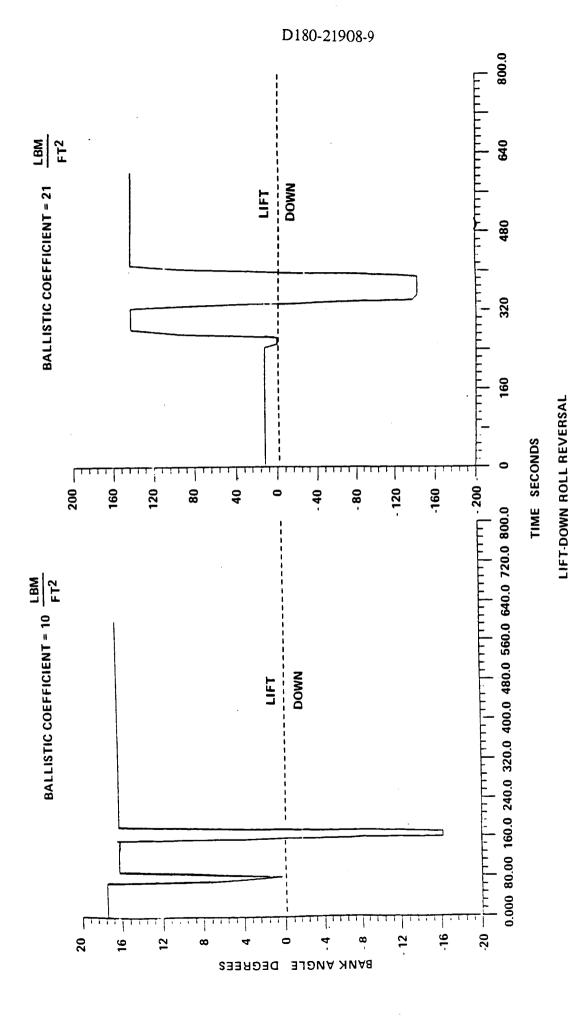


Figure 4.1-11 Effect or Ballistic Coefficient on OTV Bank Angle

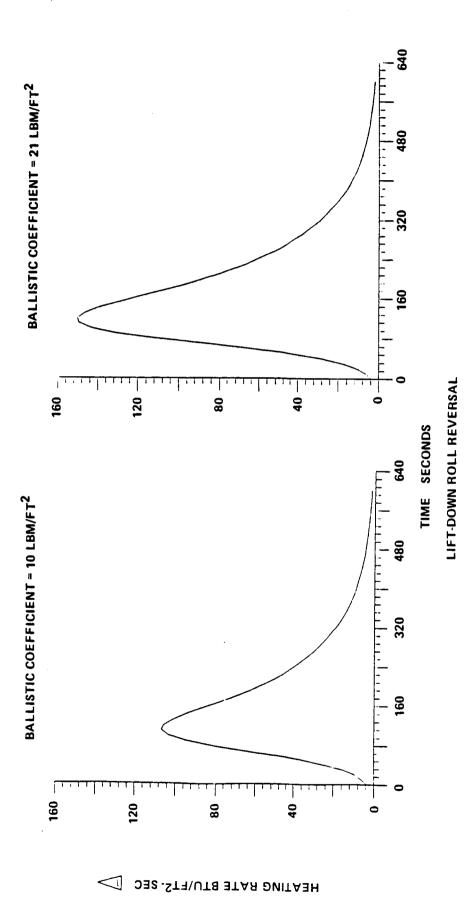


Figure 4.1-12 Effect of Ballistic Coefficient on Heating Rate

[> AT STAGNATION POINT OF A 1 FT RADIUS HEMISPHERE

philosophy are shown in figure 4.1-13. The effect of ballistic coefficient on insertion delta-v is again shown to be small. For the lift-down command profile, the maximum heating rate (figure 4.1-12) is again found to be about 1.4 times greater for the higher ballistic coefficient vehicle. In comparing the runs using the different roll direction command profiles, it is seen that lift-up results in about a 2.3 nm deeper atmospheric penetration (figures 4.1-7 and -10) and resulting higher heating rates (figures 4.1-9 and -12). The maximum heating rates for the lift-up reversals are about 1.3 times greater than those for the lift-down reversals.

4.1.5 Conclusions

The above data indicates that the choice of lift-down reversal is the likely guidance philosophy. However, there are other factors to be considered. The lift-down trajectories have longer paths through the atmosphere and may be subject to greater variation in atmospheric density fluctuations. The question is whether there is greater variation vertically or horizontally in the atmosphere. Also, the longer pass through the atmosphere results in the application of a lower heating rate but for a longer time which may result in higher temperatures. Another consideration is the possible impact on mission success. In the case of unexpectedly large atmospheric perturbations, a lift-up reversal philosophy may insure atmospheric exit, rather than capture.

The conclusions from the aeroguidance analysis are that an L/D vehicle of 0.12 has sufficient capability to correct for atmospheric disturbances and entry errors. The increase in ballistic coefficient from 10.2 lbm/ft**2 has a minimal effect on the required propulsive delta-v requirements for post-aeromaneuver circularization. The primary effect of the change in ballistic coefficient is the increased susceptibility to atmospheric perturbations and the increased peak heating rate. These effects can be reduced, however, by considering the total mission in the choice of the control variables and roll philosophy.

4.2 AEROTHERMAL ANALYSIS

The relatively high ballistic coefficient and concomitant heating rates associated with the reentry of the propulsion/avionics (P/A) module of the partially reusable OTV have been assessed with regard to heat shield material compatibility. The left hand portion of figure 4.2-1 shows the predicted maximum, nominal, and minimum peak heating rates for P/A module reentry. The reason there is a wide band of peak heating rates shown is a result of inadequate understanding of the phenomena of nonequilibrium radiation and surface catalytic properties that become increasingly important as heating

			REQUIRED DELTA-V (FT/SEC)	/ (FT/SEC)	
VEHICLE	REVERSAL DIRECTION	TO RAISE PERIGEE TO 150 NM.	TO CIRCULARIZE AT 150 NM	TO CORRECT ORBIT PLANE TO i=28.50, Ω = 00	TOTAL TO TO INSERT INTO TARGETED ORBIT
P/A MODULE B.C. = 21.1 LB /FT ²	LIFT UP	37.7	0.01	0	7.77.8
LOGISTICS MODULE B.C. = 10.2 LB/FT ²	LIFT	369.3	0.02	0	369.3
P/A MODULE B.C. = 21.1 LB/FT ²	LIFT	216.5	0.03	0	216.5
LOGISTICS MODULE B.C. = 10.2 LB/FT ²	LIFT	211.1	0.10	o	211.2

Figure 4.1-13 Nominal Trajectory Insertion 'Velocity Increment

필급	<u> </u>	=	2
	MIN •	09	
PREDICTED PEAK HEATING RATES (BTU/FT ² —SEC)	WON	87	
	MAX •	135	

		HEALING	HAIE (BI	HEALING RAIL (BIU/FI4-SEC)
			1990 T	1990 TECHNOLOGY
TPS TYPE	TPS LIFE (MISSIONS)	CURRENT TECHNOLOGY	NORMAL GROWTH	NORMAL ACCELERATED GROWTH
FLEXIBLE SURFACE INSULATION (FSI)	70	4—6 (AFRSI)	30	09
	-	8-9	35	20
RIGID SURFACE INSULATION (RSI)	20	38 (FRCI)	09	06
HIGH DENSITY REFRACTORY (HDR)	20	70 (ACC)	06	150
ABLATORS	•	> 500	1	1.

OBSERVATIONS

- EXPENDABLE ABLATIVE HEAT SHIELD MAY BE BEST CHOICE
- LOWER TECHNICAL RISK THAN RSI
- LOWER RISK AND WEIGHT THAN HDR
- TECHNOLOGY ADVANCES ARE NEEDED IN THESE AREAS:
- AEROTHERMAL ENVIRONMENT PREDICTION TECHNIQUES
- TPS MATERIALS CAPABILITY

Figure 4.2-1 PRS Thermal Assessment

rates increase (see section 4.7, Vol III, for additional explanation). On the right side of figure 4.2-1, four thermal protection system (TPS) materials are shown with life requirements and heating rate capability for current technology and expected 1990 technology assuming normal growth and accelerated growth. It is seen that current technology requires the use of an ablator for the nominal or higher predicted heating rate. Normal technology growth by 1990 is expected to produce a high density refractory (HDR) insulation capable of withstanding the nominal predicted heating rate. Accelerated growth to 1990 is expected to provide the capability for HDR to withstand the maximum predicted heating rate and the capability of rigid surface insulation (RSI) to withstand the nominal heating rate.

Based on the predicted heating rates, their uncertainty, and the state-of-the-art for TPS, an ablative heat shield is recommended for the P/A module. A reusable insulation may be used if technology advances are made in the areas of aerothermal environment prediction techniques and reusable TPS materials capability.

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5.0 ORBITAL SUPPORT

This section describes the orbital support associated with a space based ballute braked OTV that performs the Rev. 9 mission model and uses both CLV and STS launch vehicles to support the OTV missions.

5.1 SPACE STATION ACCOMMODATIONS AND OPERATIONS

5.1.1 Support Facility Location

The key issue associated with a SB OTV performing the Rev. 9 mission model was how many orbital support facilities should be used. The model involved 423 OTV flights with the majority of these having a destination of synchronous orbit (19,323 nm, 0 degree inclination). There were 131 other missions each involving 10K lbm payloads going to 19,323 nm/63 degrees and 16 missions involving 4K lbm payloads going to 4000 nm/90 degrees.

Several orbital support facility options were investigated. One was to have a single facility located at 250 nm/28½ degrees and be part of the Space Station. The second option was to have two facilities with one being at the Space Station to support the GEO missions and another at 200 nm/57 degrees to support the high inclination missions. The inclination of the second facility was selected because it was the closest to the mission orbit involving the most OTV flights that could still be reached by the STS. Discriminators between the two options included delta propellant launch cost, delta facility cost, and delta crew logistics cost.

The high inclination support facility is characterized in Figure 5.1-1. The structure and major subsystems are assumed to be derived from the Space Station. OTV support accommodations include a hangar and maintenance equipment, propellant storage and transfer provisions, and a small common module to house the support crew while at the facility.

A summary of the key characteristics concerning OTV propellant requirements and crew logistics is presented in Table 5.1-1. The amount of propellant that must be launched to support is space based OTV was found to be greater for the single facility option. This occurs because the high inclination missions require large plane changes to reach the mission orbit and return.

Two options were evaluated concerning logistics and manning for the high inclination facility. Logistics flights for the permanently manned option (90 day staytimes) required the full capability of an STS. STS logistics flights to support 2 week stay times in the man-tended mode had significant payload margin and thus took up

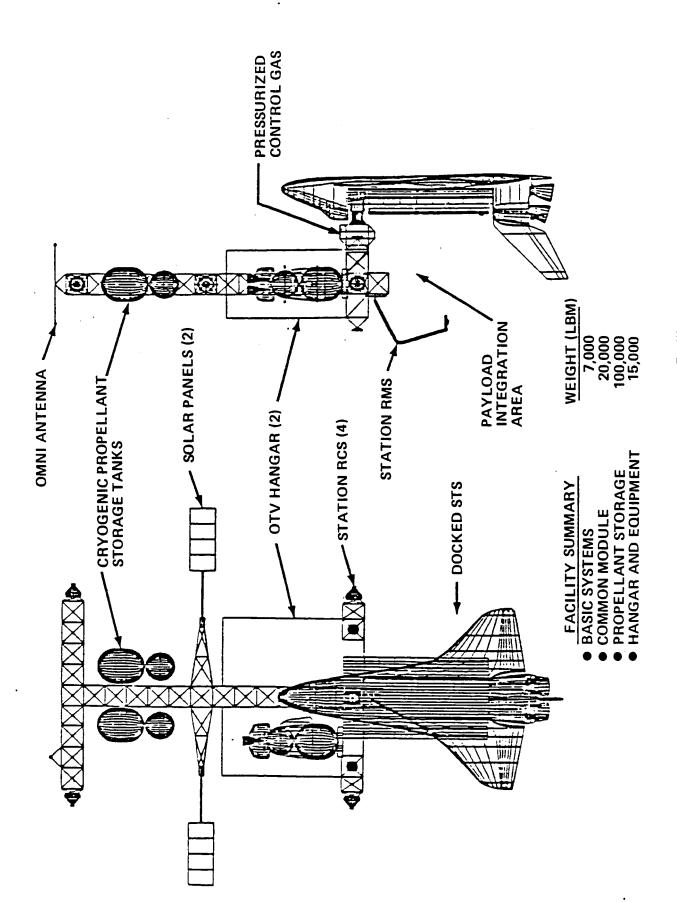


Figure 5.1-1. LEO High Inclination Support Facility

Table 5.1-1. SB OTV Orbital Support

PROPELLANT REQUIREMENTS (K LBS)

	TOTAL 1	7036	5280)
IISSION	K/630 4K/900	61.4	38,3	
PEK	▼ 10K/63 0	42.7	33.0	
	PAYLOAD - 10K/630	(LB/INCL.)		(LAUNCH FROM 57° FACILITY)
		• 1 FACILITY	•2 FACILITIES	(LAUNCH FROM

- LOGISTICS/MANNING (57 DEG FACILITY)
- PERMANENTLY MANNED
- 5-6 PERSON CREW (3 FOR SERVICING OTV)
 - 4 LOGISTICS FLIGHTS PER YEAR
- \$292 M/YR
- **MAN TENDED**
- ORBITER REMAINS AT FACILITY 2 + WEEKS PER OTV FLIGHT
 - 6 PERSON SERVICING CREW
- ORBITER HAS 2 + LESS WEEKS FOR GROUND PROCESSING
 - \$180 M PER YEAR IMPACT

V SELECTED

1> INCLUDES PROP HANDLING FACTOR 1.075

cargo to support the OTV flight (either the payloads or propellant). Consequently, fewer CLV flights were required. The cost shown reflects the additional ground processing effort required because the Orbiter had 2 weeks less time for ground processing. Ten STS flights were required for this mode. As a result, the man-tended mode offered the lowest annual cost.

The cost comparison of the two orbital support facility options is presented in Table 5.1-2. A single facility such as the Space Station located at 250 nm/28.5 provided the least cost and is the selected approach. Although this approach had more propellant delivery launch cost because of greater OTV delta V requirements (plane changes) there was a significant savings in not having to duplicate facility equipment and less logistics cost to support a crew at the high inclination facility. (Note: there is logistics and facility cost at the low inclination facility but these are the same for both support options and thus delta costs are used).

5.1.2 Selected Accommodations and Operations

The selected approach for providing the facility to support a SB OTV was to add the necessary accommodations and operational capability to the NASA Space Station located at 250 nm/28.5 degree. The key features of the accommodations and operations are summarized in Figure 5.1-2. The description of both the accommodations and operations is essentially the same as that provided in Volume IV and Volume II, Book 4, respectively. The accommodations include common module equipment including an airlock and control consoles for OTV support, addition of one or two hangars for providing OTV environmental protection as well as a maintenance location, external servicing equipment, and propellant storage and transfer provisions. Further definition of the hangar for the ballute braked OTV is shown in Figure 5.1-3. Further description of the propellant storage system and tanker can be found in Section 5.2.

Processing an OTV for each flight involves inspection, maintenance, servicing, payload attachment and checkout, and loading of consumables. Based on a combination of the work performance in the OTV concept study and on the OTV Operations study (Boeing for KSC) a total of 313 IVA hours and 52 EVA hours are required to prepare an OTV for its flight. Per study groundrules of \$81,700 and \$18,700 per crew hour for EVA and IVA, respectively, a turnaround cost of \$10 million per flight occurs.

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•15 YEARS

2 FACILITIES	3360	009	2700
1 FACILITY	4105		
	PROPELLANT DELIVERY	●△ FACILITY (DDT&E AND PROD)	◆ △ LOGISTICS/MANNING

CONCLUSION: SELECT 1 FACILITY

1,500 LBS

8,000

8,500

247,800

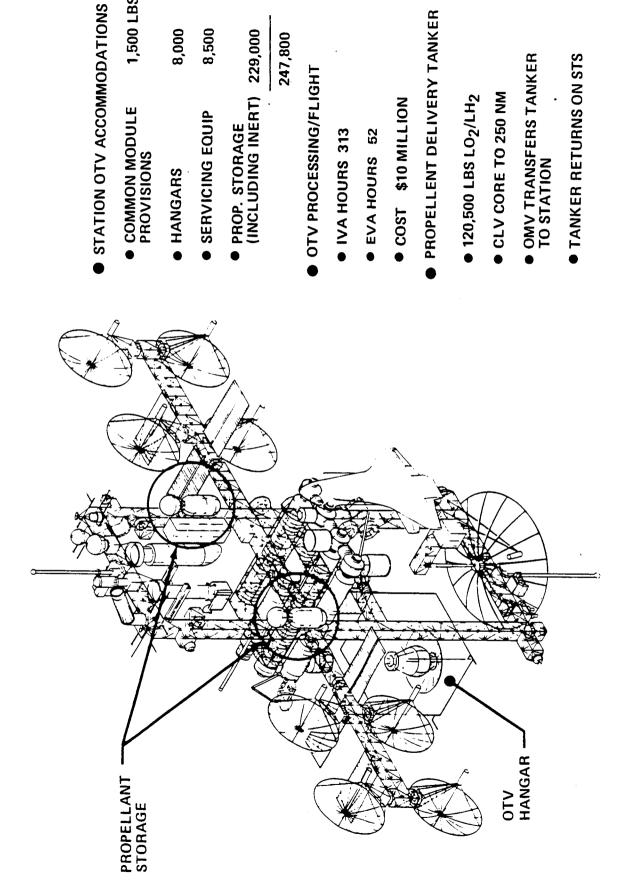
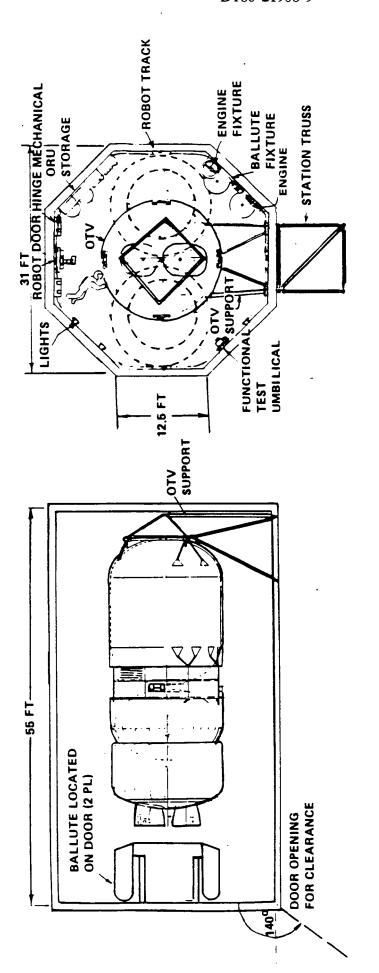


Figure 5.1-2. Space Basing Support Phase II - STS + CLV



NOTE: ASTRONAUT FOR SCALE ONLY

Figure 5.1-3. Ballute OTV Hangar

5.2 SB FRS PROPELLANT LOGISTSICS

This section discusses the propellant requirements, tanker and propellant storage associated with the SB FRS for scenario 2 of the Revision 9 mission model.

5.2.1 Propellant Requirements

The propellant required by the SB FRS is indicated by the lower line in figure 5.2-1 in terms of annual mass for the years 1995 through 2010. Earlier studies have shown that average losses due to boil off, feed line and OTV chilldown, and nonrecoverable OTV and tanker residuals are 7.6%. The upper line of figure 5.2-1 indicates the annual requirement for propellant delivery by the tankers to account for these losses.

5.2.2 Propellant Tanker

CLV payload capability to the Space Station altitude (250 nm) is 139,000 lbm. The tanker has been defined that takes full advantage of the CLV capabilities and can be returned in the Orbiter cargo bay. Tanker dimensions are shown in figure 5.2-2. The tanker is capable of delivering 120,478 lbm of LO2/LH2 (discounting residuals and boiloff). Also required by the OTV, and provided by the tanker, are hydrazine and nitrogen for RCS and pressurization use. Helium is provided for tanker pressurization during Orbiter return. The tanker is composed of an outer shell of graphite - epoxy, tanks of 2219 aluminum with 0.707 elliptical domes, and cylindrical sections. Spherical 2219 aluminum tanks are employed in the intertank and forward of the LH2 tank for helium, nitrogen, and hydrazine storage. Cryo tank insulation is DAK with nylon scrim; 40 layers for each tank. ASE provides the tanker-to-CLV transition and is sized to support a cantilevered fully-loaded tanker under worst case launch loads. A weight summary is shown in table 5.2-1.

5.2.3 Propellant Storage at Space Station

Storage of cryogenic propellants at the Space Station involves three issues: storage capacity required, storage tank design to maximize utility and minimize losses, and location of the tank(s) on the Space Station. The latter subject is considered in the purview of the Space Station design and is not addressed here. OTV concerns are that the propellant be available when needed by the OTV and that propellant transfer lines not be excessively long thereby causing increased childown losses.

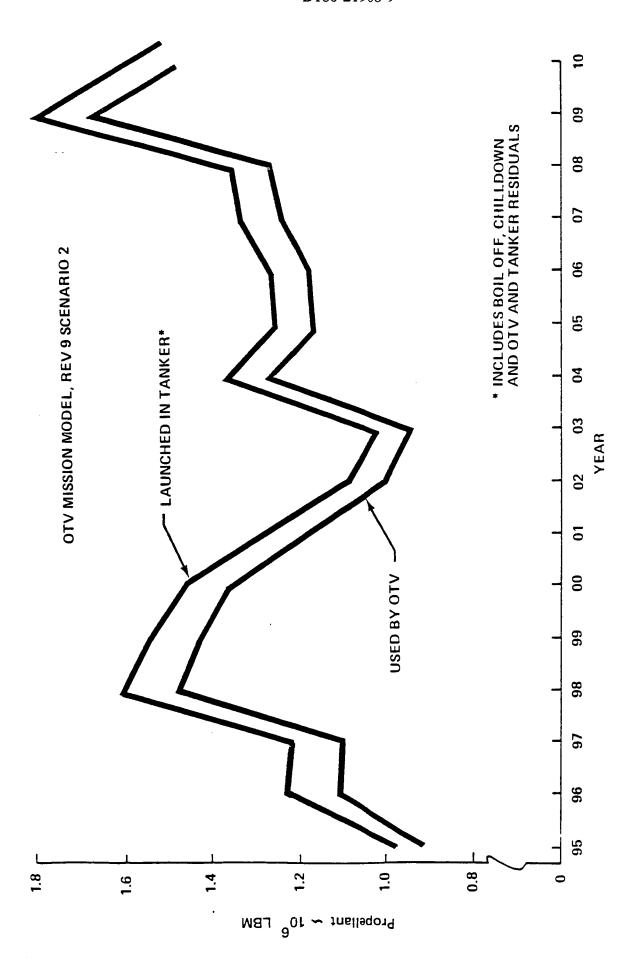


Figure 5.2-1. SB FRS Propellant Usage and Tanker Launch Requirements, Scenario 2

OTV-1300

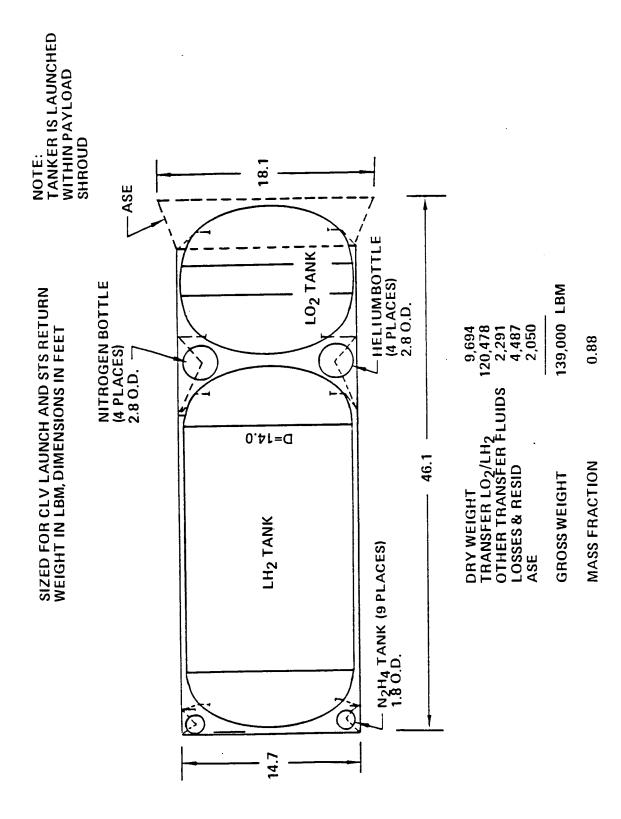


Figure 5.2-2. Propellant Tanker $Wp = 120,500 \ lbm$

Table 5.2-1. Summary Weight Statement for 120.5K LO₂ /LH₂ Propellant Tanker

		VEIGHT (LB	M)
STRUCTURE		4,841	
THERMAL CONTROL		388	
AVIONICS		185	
ELECTRICAL POWER		194	
MAIN PROPULSION FLUIDS AND 'GASES TRANSFER SYSTEM		2,091	
REACTION CONTROL FLUIDS AND GASES TRANSFER SYSTEM		759	
ELECTRICAL POWER FLUIDS AND GASES TRANSFER SYSTEM		-	
WEIGHT GROWTH MARGIN		1,236	
(TANKER MODULE DRY WEIGHT)			(9,694)
MAIN PROPULSION TRANSFER SYSTEM RESIDUAL FLUIDS AND GASES		2,630	
REACTION CONTROL TRANSFER SYSTEM RESIDUAL FLUIDS AND GASES		250	
ELECTRICAL POWER TRANSFER SYSTEM RESIDUAL FLUIDS AND GASES		-	
(TANKER MODULE END-OF-TRANSFER WEIGHT)			(12,574)
MAIN PROPULSION FLUIDS AND GASES LOSSES		1,607	
RCS FLUIDS AND GASES LOSSES		-	
EPS FLUIDS AND GASES LOSSES		-	
TRANSFER FLUIDS AND GASES		122,769	
(MPS)	120,478		
LO ₂ /LH ₂ (EPS)	- .		
GH _e	15		
N ₂ H ₄	1,747		
GN ₂	529		
(TANKER MODULE GROSS WEIGHT)			(136,950)
CONTRACTOR-FURNISHED ASE		2,050	
GOVERNMENT-FURNISHED ASE		-	
(LAUNCH WEIGHT)			(139,000)
TANKER MASS FRACTION		0.880	

5.2.3.1 Propellant Storage Capacity Requirements

The OTV propellant storage tanks at the Space Station must have the capacity to contain the following:

- o propellant from one tanker with storage tank peak residuals
- o propellant sufficient to accomplish the two most demanding missions during unmanned era (scenario 2, 1995 to 2002)
- o propellant sufficient to accomplish the two most demanding missions and a manned GEO rescue mission during the manned era (scenario 2, 2002 to 2010)
- o an allowance over the foregoing of 6% for chilldown and boiloff.

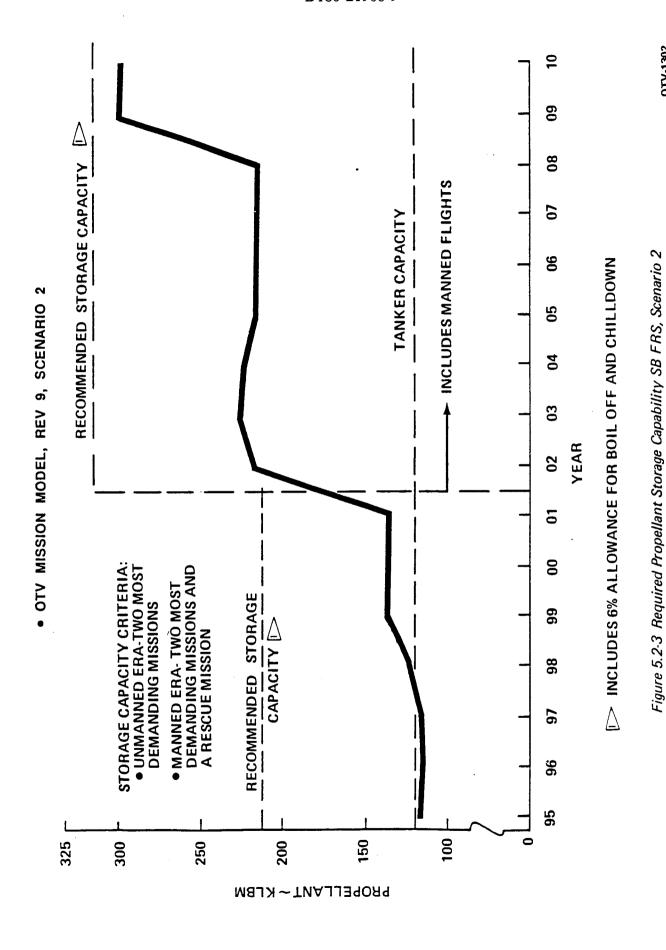
An additional criterion used in storage tank sizing was that loss of a single storage tank shall not negate OTV capability.

An analysis of scenario 2 missions for propellant requirements for the unmanned and manned eras (as defined in the previous paragraph) has resulted in the quantity history shown in figure 5.2-3. Note that the requirement and the tanker capacity are nearly the same for the first 3 years. The large increase between 2001 and 2002 reflects the transition from the unmanned era to the manned era and the concomitant rescue mission capability. The increase of 2009 and 2010 is due primarily to the unmanned lunar surface delivery missions.

5.2.3.2 Storage Tank Design

LH2/LO2 propellant storage tank sizing was determined based on the following criteria:

- o one tank failure shall not negate OTV capability (see also section 5.2.3.1)
- o the set shall be deliverable and returnable by the Orbiter
- o all tanksets shall be the same size and design thereby minimizing the production cost.



151

The storage tanks are delivered to the Station empty of propellant but with helium at 20 psia for stabilization of the light weight structure. Launching the tanks empty is desired to obviate the structure otherwise required to support the propellant weight. This added structure would contribute to the heat paths and increase boiloff as well as Station mass. Additionally, empty tanks obviate cryo-pumping concerns and the need for either an MLI purge or the use of a Dewar.

Referring again to figure 5.2-3, it is seen that the peak propellant requirement in 2009 and 2010 is 299,000 lbm. With a 6% allowance for boiloff and chilldown, the propellant storage capacity requirement is 317,000 lbm. The determination of storage tank size was guided by the idea that, while at least two are required for redundancy, fewer large tanks are thermally more efficient than more smaller tanks as long as a tankset will fit in the Orbiter payload bay. To this end, a tankset capacity of 106,000 lbm was defined with three sets required for the manned era and two for the unmanned era. Thus, as indicated in figure 5.2-3, two tanksets result in a storage capacity of 212,000 lbm initially and, with a third tankset, 318,000 lbm after the onset of manned OTV use.

The tank designs that meet the foregoing criteria are shown in figures 5.2-4 and 5.2-5 for the LH₂ and LO₂ storage tanks, respectively. These tanks incorporate a 2219 aluminum pressure vessel 13 feet in diameter, 120 layers of MLI, two vapor-cooled shields, fiberglass strap supports, and a 14.33 foot diameter debris/meteoroid isogrid protection shell. The lengths of the LH₂ and LO₂ tanks with insulation and debris shield are 34 and 15.7 feet, respectively. Liquid acquisition is achieved, for both LH₂ and LO₂, using 8 channels on tank meridians with two screens with 325 x 2300 mesh on one side of the channel. Tank capacity is 15,470 lbm with 5% ullage and 90,383 lbm with 2% ullage for the LH₂ and LO₂, respectively. The tank weights with ASE are 7348 and 3463 lbm for the LH₂ and LO₂ tanks, respectively.

5.2.3.3 Propellant Transfer

Propellant transfer from the tanker to the storage tanks or from the storage tanks to the OTV is shown, schematically, in figure 5.2-6. Propellant transfer is effected by imposing a pressure differential between the tank being evacuated and the tank being filled. The screen liquid acquision system assures that only liquid is transferred. Propellant childown and boiloff gases are compressed and stored at 2000 psia. These compressed gases are used for propellant transfer or are stored until disposition can be accomplished.

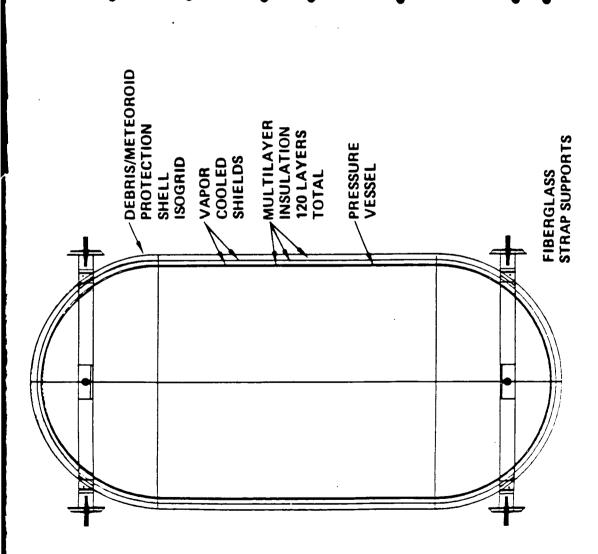
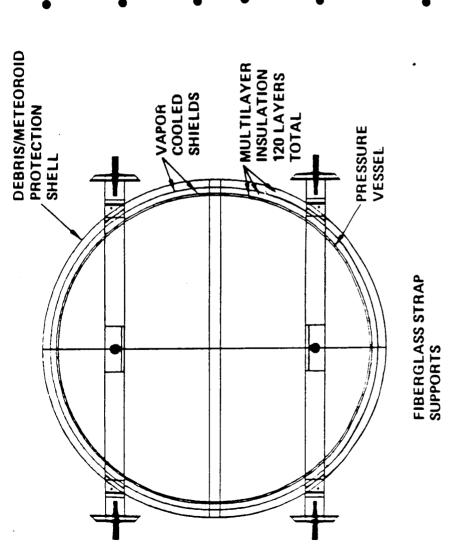


Figure 5.2-4 Space Station Hydrogen Storage Tank Baseline Concept

DESIGN PARAMETERS

- PRESSURE VESSEL
- DIAMETER, 13 FT LENGTH, 32.2 FT WEIGHT, 1609 LBM
- **DEBRIS/METEOROID SHELL**
 - DIAMETER 14.33 FT VEIGHT, 1833 LBM
- CAPACITY AT 17.5 PSIA 15,470 LBM WITH 5% ULLAGE
- **NSULATION SYSTEM** 120 LAYERS MLI
- 2 VAPOR COOLED SHIELDS WITHIN MLI BOILOFF 7 LBM/DAY
 - WEIGHT, 1266 LBM
- LIQUID ACQUISITION SYSTEM
- 8 CHANNELS ON MERIDIANS CHANNELS 8 IN. BY 2 IN.
- 2 SCREENS 325 x 2300 ON ONE SIDE **OF CHANNEL**
 - WEIGHT, 852 LBM
- TOTAL TANK WEIGHT, 6394 LBM
- ASE WEIGHT 954 LBM



DESIGN PARAMETERS

- PRESSURE VESSEL
 - DIAMETER, 13 FT
 - LENGTH, 14.2 FT
- WEIGHT,481 LBM
- DEBRIS/METEOROID SHELL
 - DIAMETER 14.33 FT LENGTH, 15.7 FT WEIGHT, 865 LBM
- CAPACITY AT 17.5 PSIA 90,383 LBM WITH 2 % ULLAGE
- INSULATION SYSTEM120 LAYERS MLI
- 2 VAPOR COOLED SHIELDS WITHIN MLI BOILOFF 13 LBM/DAY
- LIQUID ACQUISITION SYSTEM
- 8 CHANNELS ON MERIDIANS CHANNELS 4 IN. BY 1 IN. 2 SCREENS 325 x 2300 ON ONE SIDE
 - WEIGHT, 267 LBM OF CHANNEL
- TOTAL TANK WEIGHT, 2509 LBM
- ASE WEIGHT 954 LBM

Figure 5.2-5 Space Station Oxygen Storage Tank Baseline Concept

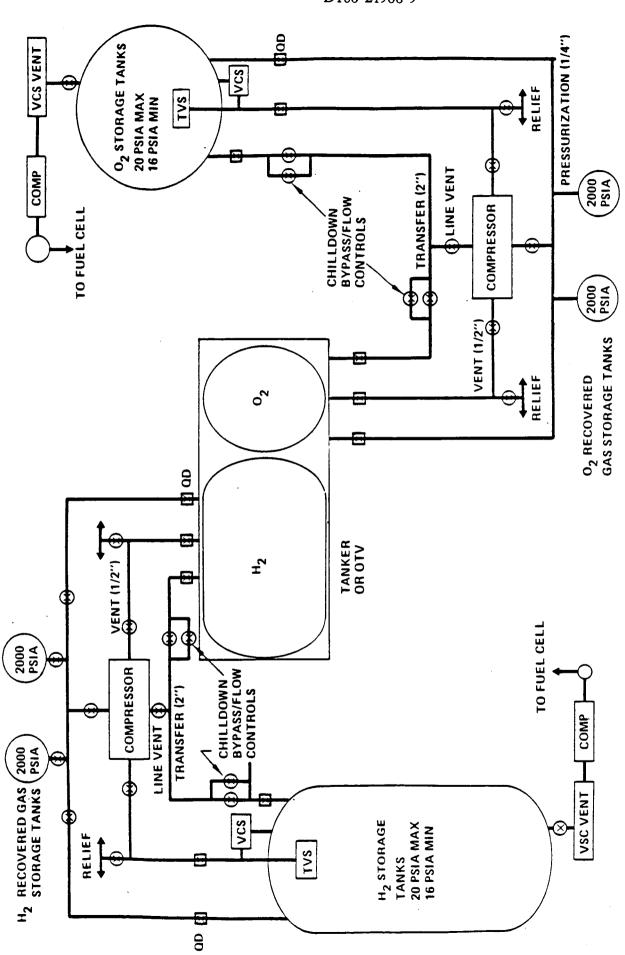


Figure 5.2-6 Propellant Transfer System Schematic

0TV-711

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6.0 OTV LAUNCH OPERATIONS

The OTV Launch Operations analysis is derived and tailored from work done by Boeing in support of the Space Transportation Architecture Study (STAS) and the KSC Orbital Transfer Vehicle Launch Operations Study. It includes:

- a. Operational scenarios based on a STAS developed Cargo Launch Vehicle and Orbiting Vehicle with return cargo capability.
- b. An analysis of timelines, facility concepts and fleet sizes.
- c. Recurring and nonrecurring OTV costs extracted from the STAS developed Ground Operations Cost Model (GOCM).
- d. An update of Space Based OTV timelines and costs based on the KSC study data.

6.1 OPERATIONAL SCENARIOS

6.1.1 Ground Based OTV Operational Scenarios

The operational scenario for a reusable ground based OTV (GBOTV) is to launch the OTV on a Cargo Launch Vehicle and to recover it with an Orbiter Vehicle. The STAS configuration used for the Cargo Launch Vehicle is the RFLY-PPA which includes a Reusable Flyback Booster - "RFLY" - coupled to a partially reusable second stage with a Propulsion/Avionics module - "PPA". The Orbiter Vehicle is the RFLY-ROI which includes the same Reusable Flyback Booster coupled to a reusable second stage which goes into orbit and has an internal payload bay -"ROI".

The reusable GBOTV ground turnaround timeline includes one shift (8 hours) to extract (recover) it from the ROI payload bay and 73 shifts to refurbish, integrate and launch it on a RFLY-PPA. No distinction is made between the ground processing of a partially reusable and fully reusable vehicle. The mating of a P/A module with a new tankset and aeroassist recovery device (partially reusable vehicle) is considered equivalent to the recertification of a used tankset and mating with a new aeroassist device (fully reusable vehicle). The equivalency is assumed because of the uncertainty or cryogenic tankset recertification requirements. The only experience with reusable space qualified cryogenic tanks is that with the STS Orbiter PRSD tanks which are entirely different from those proposed for an OTV.

The recovery scenario for a GBOTV has the used OTV's parked in low earth orbit until there are sufficient OTV's to fill the ROI payload bay - 5 P/A modules or 2 OTV's. The "parking" and resultant delay has a very definite effect on OTV fleet size.

The expendable GBOTV processing is based on existing upper stage processing with adjustments taken for design improvements, learning, and economies of scale due to higher launch rates. The processing of the aeroassisted payload module, used on those missions requiring a return, is not included in the expendable GBOTV processing effort.

6.1.2 Space Based OTV Operational Scenario

The Space Based OTV (SBOTV) scenario includes the ground processing of either a reusable tanker or an expendable tankset, depending on the SBOTV configuration. The tanker processing scenario includes a recovery, refurbishment/recertification, and integration with the launch vehicle. The tankset processing scenario includes the assembly and checkout of the new tankset, an integration with the payload, and an integration with the launch vehicle.

6.2 GB OTV OPERATIONS ANALYSIS

Figure 6.2-1 shows a typical ground based OTV flow. It is extracted directly from the KSC Orbital Transfer Vehicle Launch Operations study final report dated March 7, 1986. The flow depicted is the flow used for the OTV Launch Operations analysis. The details of the flow can be found in Volume 3 of 5, Appendices A and B with a manpower and time summary in Volume 5 of 5, Appendix A of the KSC study final report. Some modifications were made to the KSC timelines to make them compatible with STAS modeling and operation concepts. These modifications are noted as they occur.

6.2.1 CLV/OTV Timeline and Manpower Estimates

Figure 6.2.1-1 shows the STAS developed timeline/manpower estimate chart for a RFLY-PPA CLV modified to indicate and highlight the OTV processing timeline. The data (cost per flight, timeline, and RFLY-PPA fleet sizing) shown is that for a RFLY-PPA at a nominal launch rate of 40 per year. The time is in 8 hours shifts. The P/A module is that associated with the launch vehicle. The RFLY-PPA cargo processing concept is to encapsulate the cargo in a Large Payload Integration Facility (LPIF) and then mate the encapsulated payload to the launch vehicle in the Stacking/Integration Building (SIB) prior to transferring the integrated vehicle to the launch pad. Encapsulation includes integration of the OTV with its payload and the launch vehicle payload adapter, interface verification and installation of the payload fairing. Upon completion of the encapsulation, access to the OTV and its payload is limited to that which can be accomplished through fairing access hatches.

The OTV timeline associated with the RFLY-PPA launch vehicle is:

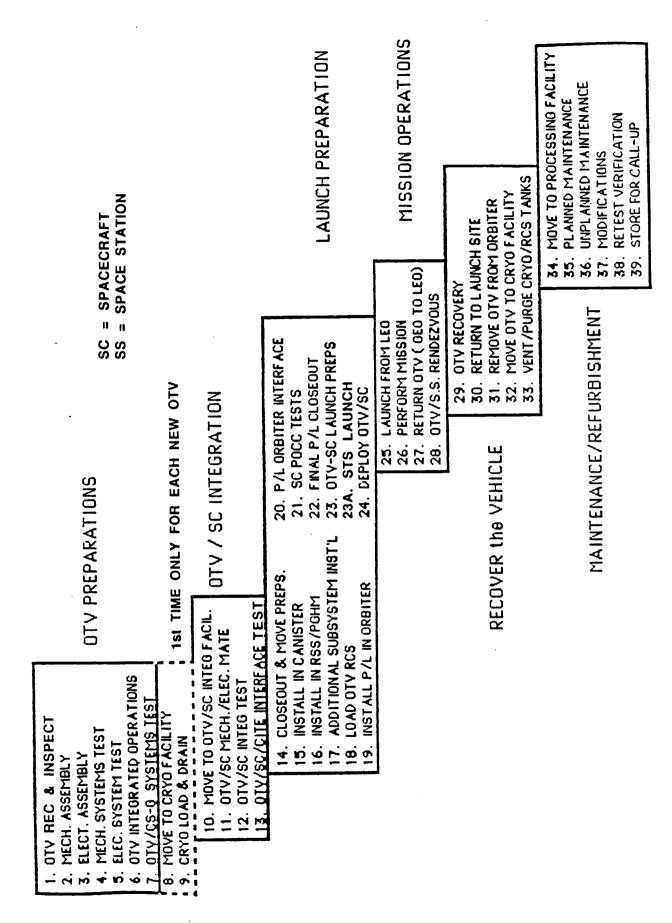


Figure 6.2-1 Typical Ground—Based OTV Flow

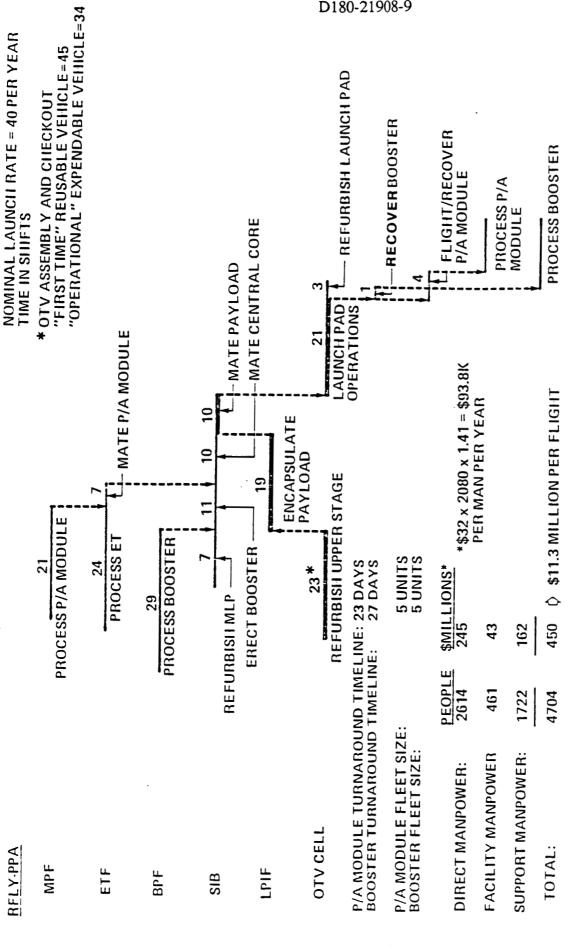


Figure 6.2.1-1 Timeline/Manpower Estimates, RFLY-PPA

- a. Refurbishment 23 shifts.
- b. Encapsulation 19 shifts,
- c. Payload Mate 10 shifts, and
- d. Launch Pad Operations 21 shifts for a total of 73 shifts.

6.2.2 STS II Timeline and Manpower Estimates

Figure 6.2.2-1 shows the STAS developed timeline/manpower estimates chart for an RFLY-ROI type STS II which is used to perform recovery of the OTV. The OTV in this case is either 5 OTV P/A modules or 2 stages. The operations take place in the Orbiter Processing Facility immediately after the Orbiter has landed and safed. The OTV removal concept is similar to existing STS concepts using a strongback to transfer the "OTV" from the payload bay to a transportation canister. The transportation canister concept is identical to the existing STS MMSE canister and transporter concept. One shift has been allocated for the removal operations.

6.2.3 Basis for Timelines

The KSC Operations Study activity called "OTV Preparations", with its nine tasks, (see figure 6.2-1) is deemed comparable to what STAS called "Assembly and Checkout". The 358.5 hours divided by 8 equals 45 shifts which transfers the timeline into equivalent whole number shifts (consistent with STAS modeling). "First time" processing of all GBOTV configurations was assumed to be equal in duration. Because "first time" processing occurs only once during the life of a reusable vehicle this timeline is not used for modeling the turnaround of a reusable OTV. A 90% learning curve for six processings was used to arrive at an "operational" processing timeline for an expendable OTV. The 90% learning curve is very consistent with past learning experience. The "six processings" is a conservative number judged to be a first year's effort. The average processing time is found by using the following equation:

Processing Time = (Duration of "First Time")(6) $\ln 0.9/\ln e = (358.5)(6)-0.152 = 273$ hours = 34 shifts

Theoretically, at an annual launch rate of 34 per year, 34 processings would be reached in the first year and (358.5)(34) = 210 hours or 26 shifts for the 34th processing. The choice of "6" represents a more realistic "ramping" during the first year. (The IUS is an operational upper stage. The current IUS launch support contract is for a capability to process 4 vehicles per year. The effort to develop a capability to process 6

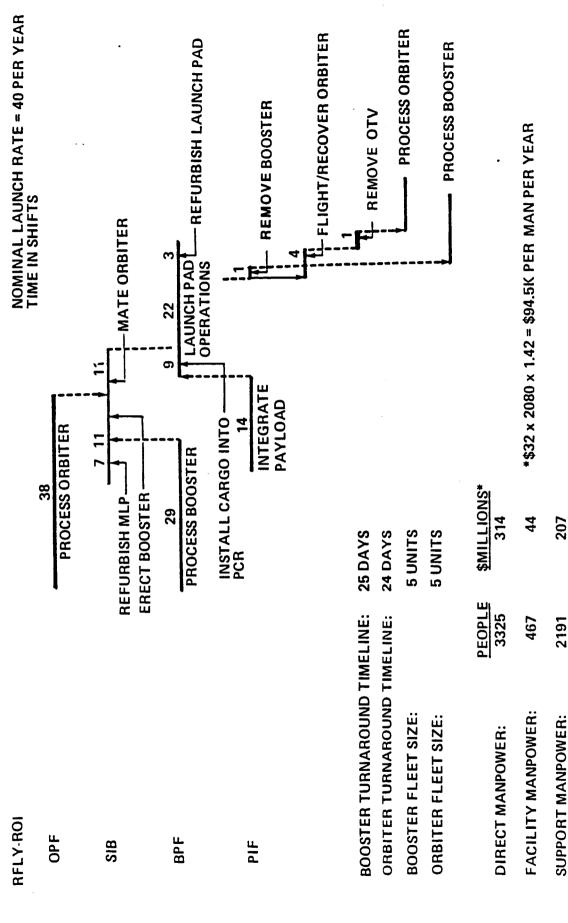


Figure 6.2.2-1. Timeline/Manpower Estimates, STS II (RFLY-ROI)

() \$14.1 MILLION PER FLIGHT

505

5983

TOTAL:

vehicles per year is being studied. The total number of IUS vehicles processed to date is four - not including Pathfinders.)

The timeline delta for an expendable GBOTV being processed on a Cargo Launch Vehicle is based on (a) OTV Preparation vs Refurbishment (34-23=+11 shifts) and (b).no recovery (-1 shift) for a total delta of +10 shifts.

The KSC Operations study activity called "OTV/SC Integration", tasks 10 through 14, is part of the STAS "Payload Encapsulation" for the CLV. It is followed by the installation and closeout of the payload fairing. The resultant payload encapsulation time is:

Tasks 10 through 15	79	Hours
Install and Align Fairing	24	Hours
Install Nose Cap	8	Hours
Closeout Fairing Ordnance	8	Hours
Remove Access Platforms	_ 16	Hours
Remove Payload from Cell	8	Hours
Transport to SIB	_8	Hours
TOTAL 151 Hours or	19	Shifts

The KSC study "Launch Operations" tasks are applicable to integration at the launch pad with a launch vehicle having an orbiter with an internal payload bay (existing STS procedure). The timeline used in this analysis is that applicable to the STAS Cargo Launch Vehicle (10 + 21 = 31 shifts) and is extracted from STAS.

"Mission Operations" was considered a function of the Control Segment, not the Ground Segment, in STAS. GOCM did not model mission or flight operations other than to insert a time delay for fleet size determination. The OTV cost modeling is kept consistent with the STAS cost modeling.

The KSC study, "Recover the Vehicle" function included tasks accomplished during the Orbiter flight which also were not considered appropriate to the Ground Segment. Task 31 "Remove OTV from Orbiter" is deemed a function of the OTV Ground Segment and is equivalent to Recovery - 7 hours or 1 shift. Tasks 32 and 33 were noted in the KSC study as "Subject to deletion for operational efficiencies" and having zero timeline. STAS concurred with a caveat that the tankset design must eliminate the tank venting and purging requirement. STAS also considered the tasks, if required, as part of the refurbishment function.

The KSC study "Maintenance/Refurbishment" function is equivalent to the STAS "Refurbish Upper Stage" function if the following adjustments are made:

- Add a new task to "Recertify OTV Tankset", (This task is currently undefined but is a. conceptualized as a non-destruct inspection requiring no more than 40 hours to accomplish.)
- Include a time for task 36, "Unplanned Maintenance", plus task 37, "Modifications", equal to the timeline for task 35, "Planned Maintenance"
- Include tasks 6, "OTV Integrated Operations", and 7 "OTV/CS-G Systems Tests" as c. being required after the completion of the unplanned maintenance and modifications, and
- Delete task 39, "Store for Call-up". d.

The certification of the OTV tankset is an area of uncertainty which could have a wide range of impact on the reusable OTV refurbishment timeline.

The resultant Maintenance/Refurbishment timeline is:

Tasks 34 through 38	74	hours
New Task Recertify OTV Tankset	40	hours
Tasks 6 and 7	_66	hours
TOTAL	180	hours or 23 shifts

6.2.4 Timeline Analysis Summary

The results of integrating the KSC study timeline analysis with the STAS analysis are shown in figures 6.2.1-1 and 6.2.2-1. For the sake of clarity, the OTV processing timeline is summarized as follows:

OTV Assembly and Checkout

	1. First time only for reusable vehicle, or	45	shifts
	2. "Operational" expendable vehicle	34	shifts
b.	Refurbish Upper Stage	23	shifts
c.	Payload Encapsulation	19	shifts
d.	Payload Mate	10	shifts
e.	Launch Pad Operations	21	shifts
f.	Recovery		
	1. Reusable Vehicle, or	1	shift
	2. Expendable Vehicle	0	shifts
	TOTAL		
	1. Reusable Vehicle	74	shifts
	2. Expendable Vehicle	84	shifts

6.3 GROUND TURNAROUND FACILITIES

The OTV ground turnaround facilities include an OTV Processing Cell, an Integration Cell, recovery facilities and support facilities. The OTV processing cell is the facility where the OTV is assembled, refurbished and checked out. It includes the support equipment for subsystem checkout and integrated system test. The integration cell in the RFLY-PPA system is the LPIF where the OTV is integrated to its payload and the payload fairing is installed. The number of cells required is determined by the mission model maximum vehicle processing rate (flights per year). As in STAS, a single shift year is 5 shifts/week x 52 weeks or 260 shifts. The OTV maximum equivalent vehicle processing rate is determined to be 34 processings per year. The processing of a two-stage OTV is considered equivalent to two single-stage processings.

The number of OTV Processing Cells required to support 34 processings per year is determined as follows:

- a. FOR THE REUSABLE GBOTV 260/23 = 11.3 vehicle processings per year on a single shift, 5 days per week basis. A three shift operation results in a capability to process 3 x 11.3 = 33.9 vehicles per year (marginal capability with one cell). Some additional processing capability is desireable to accommodate the periodic assembly and checkout of a replacement vehicle
- b. FOR THE EXPENDABLE GBOTV 260/34 = 7.6 vehicle processings per year on a single shift, 5 days per week basis. A three shift operation results in a capability to process $3 \times 7.6 = 22.8$ vehicles per year (two cells are required).

In both configurations, a single cell does not provide the required capability to support 34 processings per year and 2 cells are provided with multiple shifts in each cell. Two cells satisfy the processing timeline plus allow some time for cell maintenance, reconfiguration and calibration.

The number of Integration Cells is influenced by the launch vehicle timeline from start of payload mate to launch. (Cell configuration is maintained until the payload is launched.) For the STAS RFLY-PPA vehicle processing on a three shift, 7 days/week basis, the delay translates to 7.4 shifts on a single shift, 5 days/week basis. The translation is computed as follows: $(10 + 21 \text{ shifts})/(3 \text{ shifts per day})(7 \text{ days per week}) \times (5 \text{ shifts per week})$ equals 7.4 equivalent cell shifts. For any GBOTV configuration, 260/(19 + 7.4) = 9.8 vehicle processings per year on a single shift, 5 days per week basis. A three shift operation results in a capability to process $3 \times 9.8 = 29.4$ vehicles per year. Again, 2 cells with multiple shifting must be provided.

While the maximum number of vehicle processings determines the required number of cells, the largest vehicle determines cell size. Thus, while a single cell may accommodate a family of OTV's it is sized to accommodate the largest of that family of vehicles. Note that we have large and small OTV's for almost every system concept.

Recovery facilities include only those equipment and accommodations unique to the OTV. The actual facility is the Orbiter Processing Facility which is part of the launch vehicle system.

Support Facilities might be available at an existing launch site. The STAS GOCM assumed that none were available and developed a support facility cost reflective of vehicle launch rate. This analysis also includes a support facility cost to account for the following support facilities:

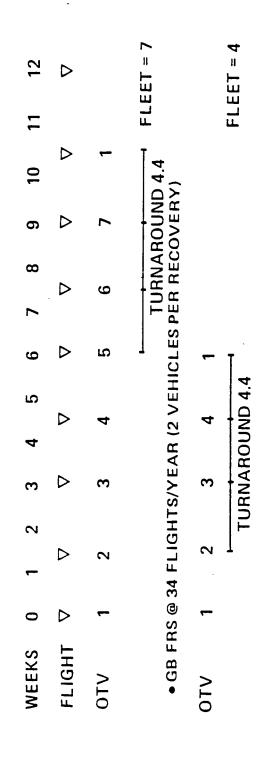
- a. warehousing,
- b. office/admin facilities
- c. shops/laboratories, and
- d. handling and transportation facilities

6.4 GB OTV FLEET SIZE

An OTV fleet size based on launch operations has meaning only for reusable configurations. Fleet size is determined by the number of units required to support the flight rate and is dependent on the turnaround timeline, the number of parallel processing facilities and the mission scenario which includes the flight timeline.

Thirty-four flights per year indicates 1.5 weeks between flights. The P/A modules for the partially reusable OTV (GBPRS) are recovered in groups of 5. The fully reusable OTV (GBFRS) is recovered in groups of 2. Figure 6.4-1 indicates the time relationship between OTV flight rate, recovery scenarios and turnaround timeline for each OTV configuration. The resulting maximum fleet size is: 7 vehicles for the GBPRS concept and 4 vehicles for the GBFRS concept. In both cases the schedule margin is so close that if we were to maintain the maximum launch rate of 34 per year for a very long period of time, additional vehicles are required for contingencies. The recovery scenarios at the given launch rate eliminate the impact of parallel facilities. A minimum of two vehicles is theoretically always available for processing.

• GB PRS @ 34 FLIGHTS/YEAR (5 P/A MODULES PER RECOVERY)



52 WEEKS/34 = 1.5 WEEK SPACING BETWEEN FLIGHTS

Figure 6.4-1 OTV Launch Operations Fleet Size

6.5 OTV LAUNCH OPERATIONS COSTS

6.5.1 Non-Recurring Costs

Consistent with ground segment costing methodology developed by STAS, the nonrecurring costs associated with launch operations are the facility acquisition costs adjusted to include the cost of design, ground support equipment, and activation. Facility acquisition costs are in 1986 dollars. The adjustment factors: a.Design (Architect and Engineer Fees): 10%

- b. Ground Support Equipment (GSE): 12%
- c. Site Activation: 32%

The design and GSE costs are percentages of the facility acquisition cost and are additive. The site activation cost is a percentage of the sum of the other three. The total adjustment factor equals (1 + 0.10 + 0.12)(1.32) = 1.6104.

The OTV Processing Cell acquisition cost is based on the size of the OTV (length, diameter and weight) using the STAS developed cost estimating relationship. The OTV portion of the LPIF acquisition cost is based on the size of the combined OTV and payload. The total LPIF cost is based on the maximum fairing size associated with the launch vehicle. The acquisition of two cells is estimated to cost 1.9 times the cost of one cell due to economies of scale, common utility connections, some sharing of areas and a common design. Allocation of the LPIF acquisition cost between the launch vehicle system and the OTV, is admittedly, quite arbitrary.

The Recovery System acquisition cost is estimated to be the same for all configurations and is fixed at \$1.0 million. It is assumed that the launch vehicle system provides the facility and the hardware to remove return cargos and that the returning OTV's are compatible with those accommodations. The resulting Recovery System acquisition cost is very minor including only unique equipment required by the OTV.

Support Facility acquisition cost is factored via a cost estimating relationship resident in GOCM from direct manpower costs. The relationship makes support facility acquisition costs sensitive to the launch rate and proportionate to the annual recurring cost. An increase in "work" results in an increase in facilities to support that "work". No evaluation is made of nor credit given for existing facilities.

OTV physical characteristics which "size" the processing facilities and, thus, determine the facility acquisition cost are given in figure 6.5-1 for each configuration analyzed. The weight includes the weight of the Airborne Support Equipment.

DRY WEIGHT*
(POUNDS)

LENGTH (FEET)

DIAMETER (FEET)

OTV

39

GBFRS

12,142 16,997 8,400

GBPRS	19	39	16,997
GBEXP	17	33	8,400
SBFRS (tanker)	15	20	10,277
SBPRS	19	39	16,997
GBEXP with A/A	18	35	13,665
cludes ASE			
Figure 6.5-1 Orbital	Figure 6.5-1 Orbital Transfer Vehicle Physical Characteristics	haracteristics	

Figure 6.5-2 lists the nonrecurring cost for each configuration analysis by facility item and total. Comments on the cost data shown include:

- a. It is assumed that any ground processing of a SBFRS vehicle occurs infrequently and is accomplished in the same facility as the tanker processing.
- b. The SBPRS has an expendable tank set. It is assumed that the tankset is integrated with the payload as part of the ground processing.
- c. The payload module associated with the "GBEXP with aeroassisted payload module" is costed as a payload (has its own process/storage facility) except for the recovery system. The need for the recovery system is deemed to be a characteristic of the OTV configuration and not a characteristic of the payload module.
- d. "Support Facilities" cost for the expendable configurations assume that the vehicles are manufactured at a steady rate and that "pipeline inventory" facilities are required to accommodate mission model launch rate variances.

6.5.2 Annual Recurring Costs

The launch operations recurring costs are defined as the manpower costs associated with processing the vehicle and are calculated on an annual bases (versus a per flight basis). The "real world" contracts for a launch processing capability to process a given number of vehicles over a given period of time. The per flight cost is then derived by dividing the total cost of the capability by the number of processings. The STAS developed costing methodology is modeled on this perception of the real world. The mission model determines how many processings per year and GOCM provides the combined fixed and variable cost of providing that processing capability.

The manpower required for a processing is divided into three categories:

- a. direct,
- b. facility, and
- c. support.

Direct manpower is defined as that manpower directly involved in the vehicle processing and is a function of launch rate and processing tasks. Facility manpower is defined as that manpower involved in the operation and maintenance of the vehicle processing facilities and ground support equipment. It is a function of facility acquisition cost. Support manpower is defined as that manpower involved in (a) the operation and maintenance of general purpose facilities and equipment including ground support systems, shops and laboratories; (b) manage-ment support including finance, personnel, administration and safety; (c) sustaining engineering; and (d) other support

TOTAL (\$ MILLIONS)	73.9	102.4	111.4	36.0	94.8	121.0
SUPPORT FACILITIES	26.2	26.4	54.9	12.5	19.8	55.4
RECOVERY SYSTEM	1.0	1.0	N/A	1.0	N/A	1.0 **
INTEGRATION CELL(S)	29.5	46.9	37.5	N/A	* 6.9	42.0
PROCESSING CELL(S)	17.5	28.1	19.0	22.5	28.1	22.6
OTV COMFIGURATION	GBFRS	GBPRS	GBEXP	SBFRS (Tanker)	SBPRS	GBEXP With A/A

* Integrate Tank Set With Spacecraft
 ** Recover Payload Module

Figure 6.5-2 OTV Launch Operations Non-Recurring Cost Comparison

services including logistics, document production and control, data storage, and other miscellaneous services. Support manpower is factored from direct manpower using ratios derived from the Rockwell International "Proposal for Shuttle Processing Contract (SPC)" staffing proposal. The derived ratio for support manpower is:

Support Manpower = Direct Manpower x 0.659

The manpower costs are priced at: \$32 per hour x 2080 hours = \$66,560 per man per year. The pricing is in 1986 dollars and includes the personnel benefits package. No fee, contingency support or government support is included for this study. (STAS included a factor of 41% for unmanned systems and 42% for manned systems.)

Figure 6.5-3 lists the annual recurring costs for each OTV configuration. It includes a manpower headcount for each manpower category and a cost per flight number. The government provided data for existing upper stages is listed for comparison purposes. It must be noted that existing upper stage data is for an earlier vintage vehicle at a much lower launch rate.

6.5.3 Cost Summary

The launch operations cost data presented was developed using a cost modeling methodology (GOCM) developed by Boeing in STAS. GOCM has been accepted as a valid tool for ground segment cost comparisons between systems. It has drawbacks similar to other parametric cost models and lacks an extensive data base. However, as a comparative tool it does allow some valid observations:

- a. Technology advancements can lower annual recurring costs. The payoff from the technology becomes most noticeable at higher launch rates. The effect of technology on life cycle costs may be considerable different when one includes the nonrecurring cost of developing the technology. This nonrecurring technology development cost when coupled with a low usage rate may preclude development of the technology.
- b. The derived maximum annual processing rate of 34 is very high when compared to past or existing upper stage processing requirements. (The Integration and Launch Support contract for IUS was for an annual processing rate of 4.) The higher processing rate accelerates the effect of learning. The learning effect is reflected in the cost comparison data.
- c. The actual costs can be drastically different from (greater than) projected recurring costs if the system usage does not attain the projected rate. Manpower

. MAXIMUM ANNUAL PROCESSING RATE = 34

. COSTS IN MILLIONS OF DOLLARS

COST PER	ţ	1.25	1.26	2.61	. 0 . 60	0.95	5 2.63	00.6 0
ANNUAL	KECUKKING COST	42.4	42.7	88.9	20.2	32.1	89.6	72.0
	TOTAL	637	642	1335	304	483	1346	3./1US 'ear
MANPOWER HEADCOUNT	SUPPORT	233	234	513	118	174	517	For Centaur G or G'/IUS aunch Rate 8 Per Year
MANPOWER	FACILITY	51	53	4	ω	46	4	Data For Centaur G or G'/II For Launch Rate 8 Per Year
	DIRECT	353	355	778	178	263	785	
010	CONFIGURATION	GBFRS	GBPRS	GBEXP	SBFRS (Tanker)	SBPRS	GBEXP With A/A	STAS Gov't Provided Launch Support

Figure 6.5-3 OTV Launch Operations Annual Recurring Cost Comparison

and facilities must be in place prior to the commencement of launch operations. The launch operational system must be suitably exercised in order to gain the required experience and learning for a truly efficient system.

This cost analysis assumes that all the "good" things have happened. It is a comparative analysis between vehicle configurations under derived operational scenarios. It is not a bid proposal.

6.6 SPACE BASED OTV OPERATIONS

The basing of an OTV at a Space Station requires launch operations for which very limited history or experience exists. The KSC OTV Launch Operation Study accomplished a more detailed analysis of space based launch operations than done during previous OTV studies which concentrated on vehicle and system performance characteristics. The data from the KSC study is used to update previous study timeline and cost data.

6.6.1 Space Operations - Turnaround

Figure 6.6.1-1 shows a typical Space Based OTV flow. It is extracted directly from the KSC Orbital Transfer Vehicle Launch Operations Study final report dated March 7, 1986. It is the flow used for the timeline and cost data update. The details of the flow can be found in Volume 3 of 5, Appendix C and D with a manpower and time summary in Volume 5 of 5, Appendix B of the KSC study final report.

Adjustments to the flow necessary to make it compatible with the analysis and costing methodology of this study are:

- a. Deleted task 7, "OTV/CS-G Systems Test" the task was identified in Volume 2 of 5 of the KSC study as being a "first flow" task only. That identification did not get transferred to the typical flow. We concur with the deletion and timeline the "OTV Preparations" task at 33 hours serial time with 66 manhours of IVA and 198 manhours of ground control station time.
- b. Deleted tasks 25 through 28, "Mission Operations" Mission Operations are costed separately from Launch Operations in this study.
- c. Estimated that the effort for tasks 36, "Unplanned Maintenance" plus 37, "Modifications" equaled the effort of task 35, "Planned Maintenance". This is consistent with the adjustment made to the "Maintenance/Refurbishment" timeline of the GBOTV flow. It results in a Maintenance/Refurbishment timeline of 51 serial manhours with 98 hours of IVA, 8 manhours of EVA and 18 manhours of

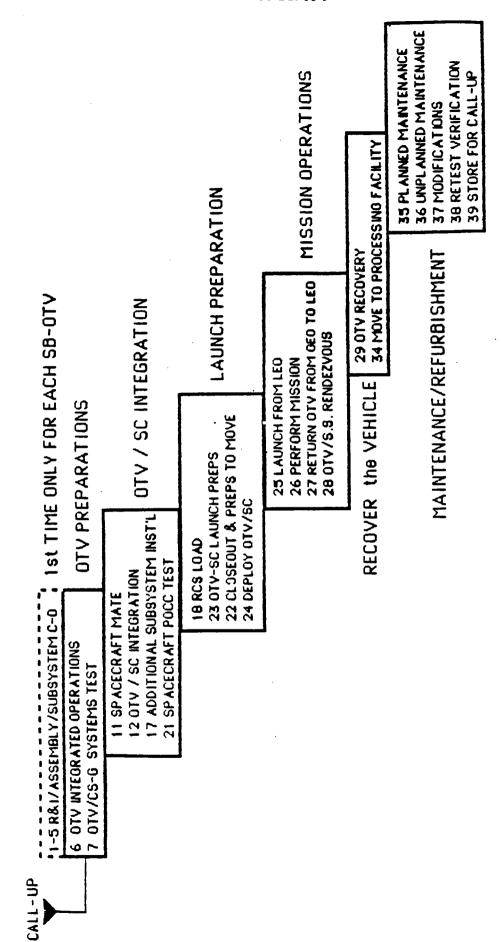


Figure 6.6.1-1 Typical Space-Based OTV Flow

ground control station time. Figure 6.6.1-2 summarizes in tabular form the space operations "Turnaround" functions and the time and manpower effort involved in each after the adjustments are made.

Figure 6.6.1-3 translates the turnaround data into a calendar day timeline based on a single shift, 8 hour per day, 7 day per week work schedule. The single shift timeline gives a theoretical maximum processing capability of 365/28 = 13 launches per year. The same people are assumed to perform the "Mission Operations" function as perform the other OTV functions requiring inclusion of that time bar. The "Missions Operations" timeline of 2.5 days (60 hours) is based on the KSC study timeline of 18 hours adjusted by mission profile data. It may be optimistic. In the real world, the calendar day timeline for mission operations could vary considerably with mission requirements.

6.6.2 Space Operations - Cost Summary

For costing purposes the processing capability of a single shift space operations is assumed to be 12 processings per year. To meet the mission model maximum rate of 34 requires a three shift operation. This implies a 9 man crew at the Space Station essentially continuously processing SBOTV's.

No differentiation is made between processing the SBPRS or SBFRS. There is some. However; the level of design detail of the Space Station, the OTV's, and the supporting equipment does not make a valid differentiation possible. The KSC study considered a "generic" OTV as does this analysis. The differentiation in this analysis is between a space based or ground based operating concept. Should it prove necessary to differentiate between a SBPRS and a SBFRS turnaround;

- a. The details of the tanker to Space Station interface and propellent transfer methodology must be developed:
- b. The interface details between the tankset and the P/A module need to be defined;
- c. The extent of Space Station automation and the use of artificial intelligence needs to be investigated; and
- d. Reusable tankset recertification requirements need to be developed.

Figure 6.6.2-1 summarizes the manpower requirements and the cost of processing an SBOTV. The numbers reflect launch operations/turnaround effort only. The significant fact which must be extracted from this data is the comparative cost of manhours at the Space Station to those on the ground. With automation and robotics it is possible to substitute IVA for EYA. However, until the cost of maintaining man in

FUNCTION	IVA (PEOPLE/ HOURS)	IVA EVA (PEOPLE/ HOURS) HOURS)	GROUND (PEOPLE/ HOURS)	SERIAL TIME (HOURS)
• OTV PREPARATIONS TASK 6	2/66	0/0	6/198	33
• OTV/SC INTEGRATION TASKS 11,12,17 & 21	2/60	2/20	6/210	35
• LAUNCH PREPARATION TASKS 18,23,22 & 24	2/99	0/0	6/297	20
• RECOVER THE VEHICLE TASK 29	2/60	2/24	6/42	36
• MAINTENANCE/REFURBISHMENT * TASKS 34 THROUGH 39	2/98	2/8	6/18	51
TOTALS	2/383	2/2	6/755	205

* Estimated that the Sum of "Unplanned Maintenance" + "Modifications" Equaled "Planned Maintenance".

Figure 6.6.1-2 SBOTV Space Operations Turnaround Data

Figure 6.6.1-3 OTV Launch Operations Space Operations - Turnaround Timeline

DTN 4464

	IVA	ĒV	VA	GROUND	JND	PER FLIGHT COST*
(MANHOURS)	MANHOURS) (\$ MILLIONS) (MANHOURS)		(\$ MILLIONS)	(MANHOURS)	(# MILLIONS)	(\$ MILLIONS) (MANHOURS) (\$ MILLIONS)
385	7.120	52	4.248	755	0.036	11.40
4 > 1	: \$ 18,700	PER M	ANHOUR			
EVA	: \$ 81,700	PER M	ANHOUR			
GRO	GROUND : \$ 4	48.00 PER MANHOUR	NHOUR			

*Launch Operations Only

Figure 6.6.2-1 Manpower Requirements Per Processing

space decreases at least tenfold, the space operations will just not be cost competitive with ground operations. Any competitive edge for a SBOTV will need to come from some other cost element.

6.7 OTV LAUNCH OPERATIONS SUMMARY

The analysis of OTV Launch Operations as with any other human operations is an ongoing, continuous process. Technology will be developed. New requirements will drive new methodology. To summarize an operation at any point in time is to merely provide a snapshot of where the operation is and in what direction it might be going. The same is true about the following:

Launch operations (the methodologies, facilitization, degree of automation, etc) are highly dependent on the launch rate. Automobiles did not become affordable until the institution of the "production line". But; for the production line to be economical, there needed to be a volume requirement and a market for that volume. This analysis assumes that OTV operations will move in the direction of a production line operation. The current upper stage launch operations are based on annual launch rates of approximately four with a high percentage of "first time" processings. The per flight processing costs indicated by this analysis are baseed on a scenario with a high annual rate and many repetitive processings.

Repetitive processings of space qualified cryogenic fuel tanks is an entirely new "ball game". The only experience base involves the STS Orbiter fuel cells. Compared to the proposed OTV tanks, they are small dewars. Reusable hydrogen tank insulation and the flight recertification requirements for large tanks are but two areas of technology which need to be developed.

The Cargo Launch Vehicle "payload encapsulation" concept minimizes total ground processing costs by minimizing the "serial impact" to launch vehicle processing. Payload encapsulation also limits access to the payload (substitute OTV). For the RFLY-PPA vehicle timeline shown, the encapsulation occurred ten or more days prior to launch. That is not too much of a departure from the current STS Orbiter timeline which closes the payload bay doors 8 to 9 days prior to launch. It is more of a departure from existing Titan timelines which integrate the cargo to the launch vehicle on the launch pad and are much more accommodating to a late access to the cargo. While not a "show stopper", the implications on vehicle and payload design should be understood.

Space based OTV processing is estimated to be 6 times more expensive per flight that any ground based OTV processing. The major cause is the cost of maintaining the man in space. The manpower cost cannot be just "wished" away by substituting

artificial intelligence and automation. The development cost needs to be considered and the cost of maintaining the hardware and software is not to be treated lightly. This analysis does not include any specific cost for hardware or software development (considered part of Space Station accommodations). Neither does it include the cost of any hardware or software maintenance (considered "wrapped" into the per hour cost of EVA and IVA).

Further assessment of automation and artificial intelligence for space based OTV processing is warranted. As the technology develops, its application must be assessed. Automation and artificial intelligence may facilitate ground based production line OTV processing. They are "enabling" technologies for space based production line OTV processing.

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7.0 MISSION CONTROL

7.1 GENERIC MISSION CONTROL FUNCTIONS

The generic functions which must be performed by the mission control system (MCS) for any vehicle class are shown in figure 7.1-1. The flight assignment function assesses mission feasibility, performs advanced mission planning, and assigns payload to a specific flight. It is the initial interface point for payload users. Subsequent payload user coordination is with the mission integration function whose responsibility includes the development of the detailed requirements definition for each OTV mission.

The major portion of the MCS activity occurs in the premission implementation functions which includes flight planning, data load preparation, and premission simulations. Flight planning performs conceptual and detailed mission design. In addition to mission design, propellant loading and flight mission rules are developed. Data load preparation uses the mission design to develop and validate the flight vehicle and flight control room software mission data loads. Stand alone and integrated system simulators are performed to assure flight readiness of personnel and procedures. Real time mission support accomplishes real time mission monitor and control including any real time mission replanning required. Post flight support includes flight evaluation and reporting including repair actions recommended for the next flight.

7.2 MISSION CONTROL COST DRIVERS

The major cost drivers for the mission control system are summarized in table 7.2-1. The first three items are highly interrelated since mission complexity and mission duration are related to the degree of reusability. For example, the expendable OTV mission is the least complex since the mission is one way (plus disposal of the spent stage). In addition, the mission is of shorter duration, nominally, because of the one way trip. Mission complexity significantly impacts the flight planning, data load preparation, and simulation and training functions. Mission duration impacts these same functions plus the additional cost of the mission communication and tracking services required to support the longer duration missions.

Manned missions are more complex missions requiring manned proficiency training and additional communications and tracking costs to support the higher data rates (voice, video, and crew systems data) of the manned mission. The use of multiple mission control centers insure higher nonrecurring and recurring costs to develop and staff them. The level of security required to be supported by the MCS similarly affects nonrecurring and recurring costs. The next 3 sections discuss how these MCS functions

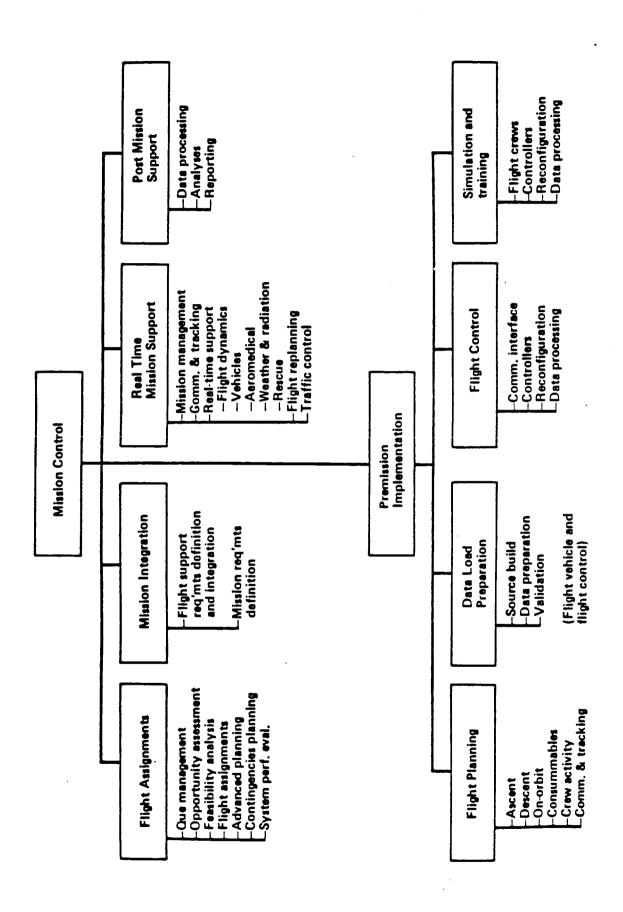


Figure 7.1-1 Generic Mission Control Functions

- DEGREE OF REUSABILITY
 —EXPENDABLE
 —PARTIALLY REUSABLE
 —FULLY REUSABLE
- MISSION COMPLEXITY
- MISSION DURATION
- MANNED/UNMANNED
- CENTRALIZED VS DISTRIBUTED CONTROL CENTERS
- SECURITY

have increased complexity as the degree of reusability and manned missions are considered.

7.2.1 Expendable Orbit Transfer Systems

The expendable orbit transfer systems are depicted in figure 7.2-1. The mission control concept for an expendable OTV is the simplest of the OTV MCS concepts. The flight planning functions are primarily concerned with the exoatmoshperic orbit transfer mission and the communications coverage required to support the mission. The vehicle data load preparation considers the predeployment orbital operations such as navigation updates and the orbit transfer for a short duration mission. Flight control is also the straight forward vehicle monitor and control approach. Trajectory replanning options are fewer since only the outbound transfer and vehicle disposal must be considered. Simulation and training must be conducted for only the flight controllers for the less complex mission. The communications and tracking elements are shown and include the TDRSS (to about the year 2000) and remote tracking stations for coverage at altitudes higher than that provided by TDRSS.

7.2.2 Unmanned Reusable Orbit Transfer Systems

For mission control of unmanned reusable orbit transfer systems, figure 7.2-2, the return mission to LEO from GEO adds additional complexities. The major differences between this concept and the expendable OTV system are shown in the boxes in figure 7.2-2. Flight planning must now include the return leg of the mission, with its aerobraking maneuver, and rendezvous with the Space Station for space basing or with a down-cargo vehicle for ground based concepts. The data load verification for the flight software is extended to a much longer mission duration and flight control and communication and tracking are extended to cover the additional mission operations and duration.

7.2.3 Manned Orbital Transfer Systems

The manned mission adds the additional mission complexities of crew activity, mission abort modes, and the increased volume of data transmitted to the ground to support the mission, figure 7.2-3. These data include voice (down link and up link), video, and data unique to manned systems. The simulation and training functions must now consider manned flight proficiency and unique training which is specific for each manned mission. The flight planning for consumables must also now consider non-propulsive consumables for additional electrical power and the crew.

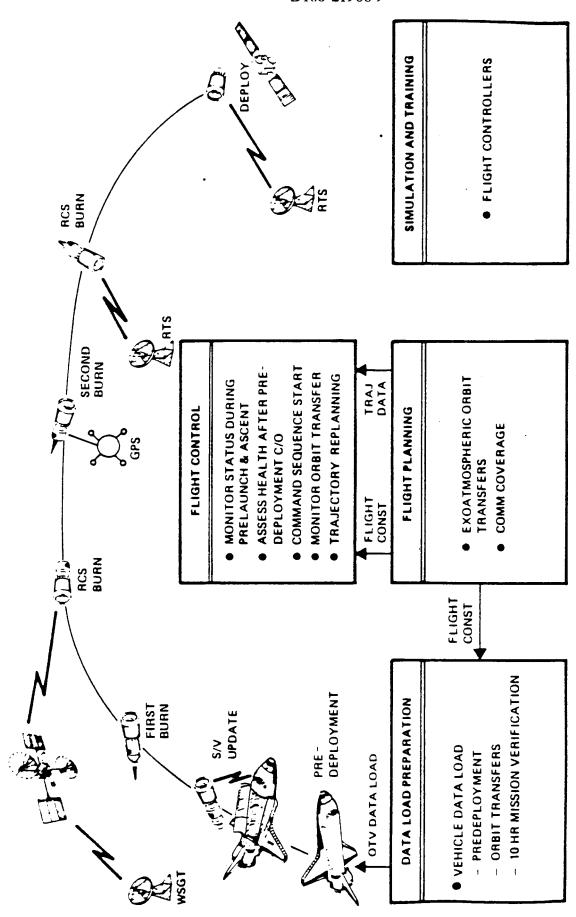


Figure 7.2-1 Expendable Orbit Transfer Systems

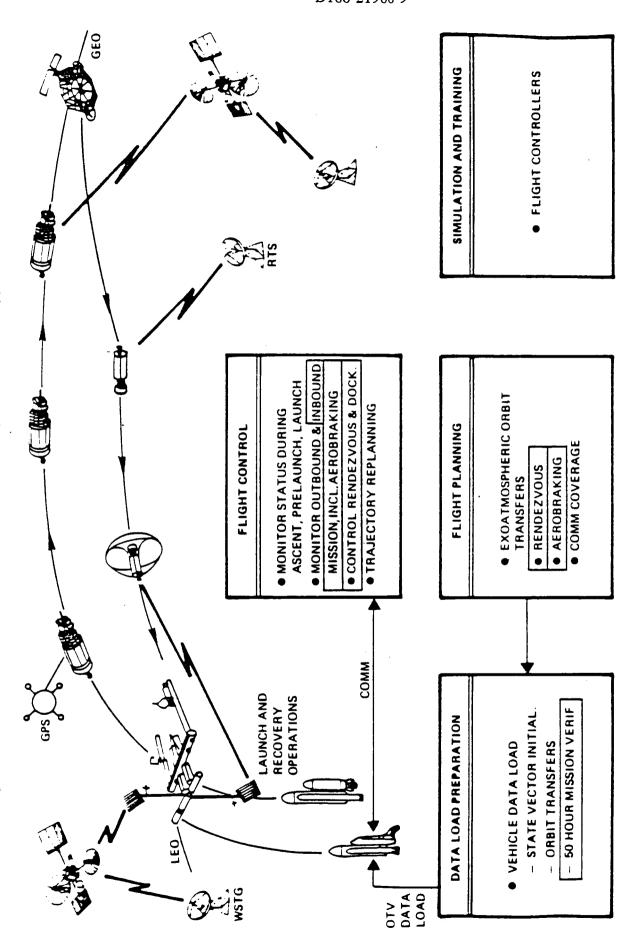


Figure 7.2-2 Unmanned Reusable Orbit Transfer Systems

Figure 7.2-3 Manned Orbital Transfer Systems

OTV-1417

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7.2.4 On Orbit Communications and Tracking Requirements

The communications and tracking system to support OTV space operations must consider not only the OTV requirements but also the orbital operations of the manned and unmanned launch vehicles as shown in figure 7.2-4. The communications link requirements shown support manned OTV operations, as well as providing payload data through the OTV communications subsystem, while the payload is attached to the OTV. This is necessary since most payloads will not deploy appendages (such as solar arrays and antennas) prior to separation from the OTV at the payload operating orbit. Also shown in figure 7.2-4 are the communications links between the ground based centers which support the OTV and payload operations.

7.3 GENERIC MANNED FLIGHT MISSION CONTROL CENTER FOR POST 2000

Based on analysis of present mission control centers and their operations, the results of STAS trades and analyses, and projections of available technologies, an integrated approach to performing the mission control fuctions was developed as illustrated in figure 7.3-1. This integrated approach ties together the various MCS functional areas through the use of a master data base management system. This central data base provides for a production-oriented operation with minimum paperwork development and flow. The outputs of each major functional area are available to subsequent users directly from the DBMS (data base management system) without intervening paperwork steps. For example, flight planning outputs are directly available to data base preparation.

In addition, projected advanced technology applications are shown in each functional area. The concept shown is applicable to the post 2000 time frame. Not all technologies shown will be available in 1995 but a phased technology implementation is proposed to eventually achieve the lower cost per flight available with the full technology implementation shown in figure 7.3-1.

7.4 MISSION CONTROL TECHNOLOGY

Technology availability and implementation analyses yielded two groupings of technologies as indicated in table 7.4-1. Those labeled as medium technologies are those which are available by 1990 for use in a mission control center (MCC) with a 1995 IOC. Those labeled as High Technology have a 1995 technology readiness and could be used in a MCC with an IOC of 2000. A trade was performed in the STAS to determine if a MCC with an IOC of 1995 should be upgraded when the high level technology became

Figure 7.2-4 On-Orbit Communication and Tracking Requirements

OTV-1416

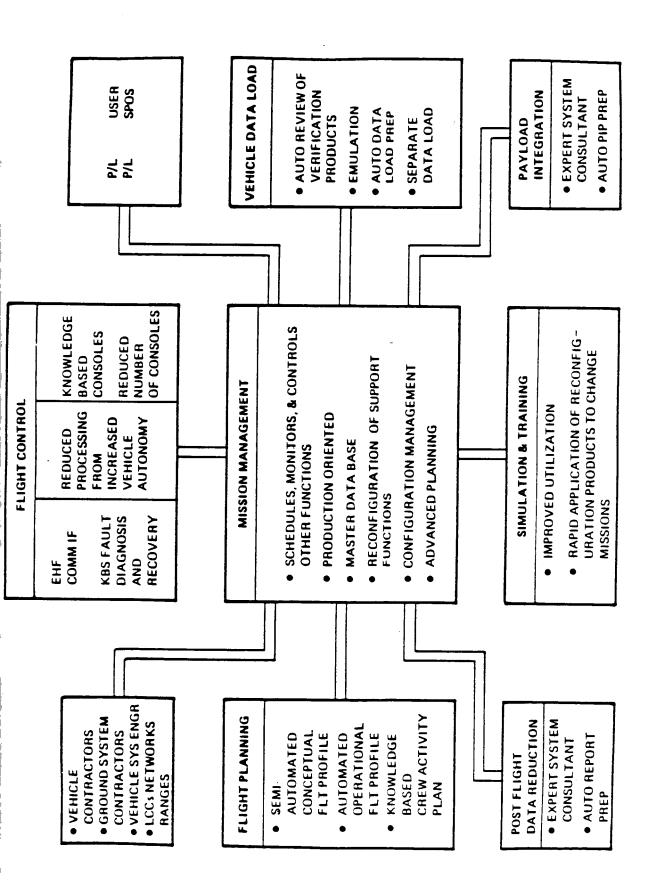


Figure 7.3-1 Generic Manned Flight Mission Control Center for Post 2000

Table 7.4-1 Mission Control Technology

	MEDIUM TECHNOLOGY LEVEL (AVAILABLE BY 1990, USE IN 1995)	HIGH TECHNOLOGY (AVAILABLE BY 1995, USE IN 2000)
GENERAL		 INTEGRATED MISSION MANAGEMENT PLANNER/SCHEDULER COMMON S/W ELEMENTS CENTRAL AI/DBMS CONTROLLER COMPUTER AIDED SW DEVELOPMENT TRUSTED COMPUTER BASE > AI
FLIGHT DESIGN	EXPERT SYSTEM SUPPORTADDITIONAL DBMS	INTEGRATED DESIGN USING AIAUTOMATIC MISSION CONSTANTS GENERATION & CHECK
DATA LOAD PREPARATION	COMPUTER AIDED DEVELOPMENTSEPARATE DATA LOAD REGIONSTANDARDIZATION	COMPUTER AIDED DEVELOPMENTSEPARATE DATA LOAD REGIONINTELLIGENT S/W VERIFICATION
FLIGHT CONTROL	 ADDITIONAL VEHICLE AUTONOMY EXPERT SYSTEM SUPPORT AUTOMATIC OPERATION OF ROUTINE POSITIONS RECONFIGURATION STREAMLINE 	 ADDITIONAL VEHICLE AUTONOMY AUTOMATIC OPERATION OF MANY POSITIONS (AI) FAULT DIAGNOSIS BY AI AUTO RECONFIGURATION
SIMULATION & TRAINING		KNOWLEDGE BASED TRAINERSAUTO RECONFIGURATION
NETWORK	LOCAL AREA NETWORKS .	 EHF 30/20 GHz 7 GBPS NETWORK SCHEDULING BY AI LOCAL AREA NETWORKS

available. The results showed that the investment cost for the upgrade could be paid back, with the cost per flight savings after upgrade, in less than 5 years at flight rates equivalent to those used for this OTV study. The nonrecurring costs and recurring costs per flight shown later reflect, in each case, upgrade of the 1995 IOC control centers.

7.5 MCS FUNCTIONAL DIAGRAM

Figure 7.5-1 shows the interrelationships between the MCS functional areas when the premission, realtime control, and post flight analysis functions are performed. Shown are each major MCS function and the major items (or data products) which flow to each successive functional area. The functional flow shown is essentially time phased right to left. Also shown are the relationships to payload users, the Launch Control Center (LCC), and the Communications and Tracking System (CTS). Sustaining engineering (both systems, software, and vehicle systems is required during the operational phase).

7.6 MISSION CONTROL COST SUMMARY

The estimated nonrecurring and cost per flight for the candidate OTV concepts are so shown in Table 7.6-1. The initial implementation costs reflect 1995 MCS IOC using technologies available in 1990. The cost of the upgrade to achieve the lower cost per flight achievable with the advanced technologies is also shown. Note the differences in the cost per flight for each vehicle class before and after the upgrade. Note also that the expendable vehicles, due to low mission complexity and duration, have the lowest cost per flight. The fully reusable vehicle cost per flight are the next highest, with the partially reusable system being the highest. In our analysis of ground and space basing impacts to MCS costs, we could find no significant differences.

7.7 MCS SUMMARY

The mission control system findings are summarized in Table 7.7-1. Of course, mission complexity and duration are the major cost drivers. MCS cost per flight will be lowest for expendables because of no requirement for vehicle control after mission completion. The partially reusable vehicle will have the highest MCS costs because of a greater number of items to be controlled during reentry; hence a greater mission complexity. It was found that, though significant, MCS costs were not discriminators between concepts.

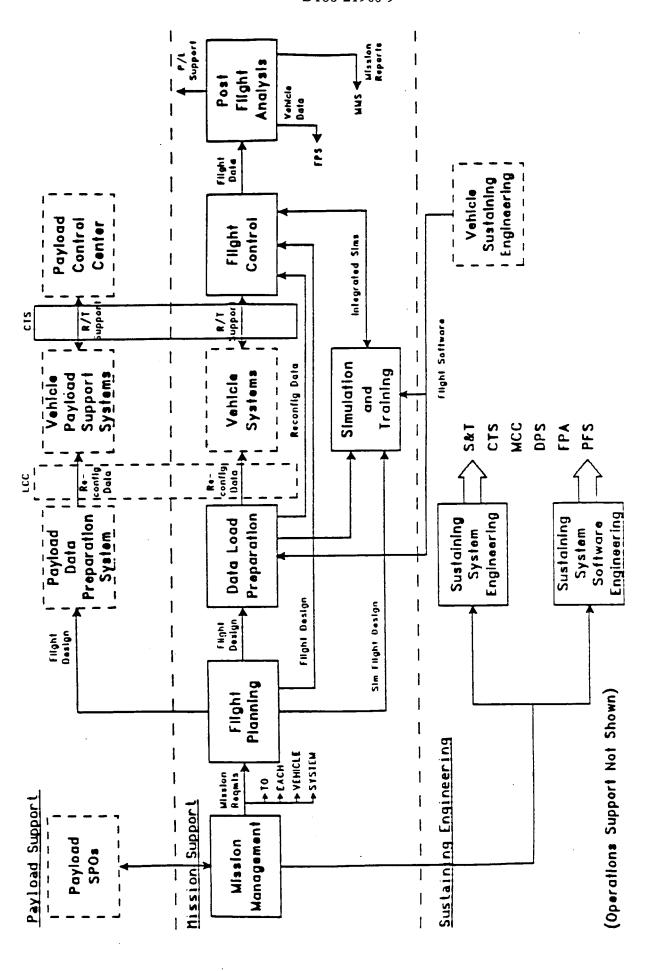


Figure 7.5-1 Mission Control Functional Diagram

OTV-1414

Table 7.6-1 Mission Control Cost Summary (1986 Dollars)

	NON-RECU	NON-RECURRING COSTS (\$M)	(V	COST PEI	COST PER FLIGHT (\$M)
VEHICLE CLASS	INITIAL IMPLEMENT (1995 IOC)	UPGRADE (2000 IOC)	TOTAL	INITIAL 1995-2000	UPGRADE POST 2000
GB FRS	576	291	867	6.01	2.95 UNMAN. 4.86 MAN.
GB PRS	634	320	954	6.54	4.04 UNMAN. 5.26 MAN.
EXPENDABLE 1 STAGE UNMAN. 2 STAGE UNMAN. 2 STAGE MAN.	399	224	623	3.88 7.76 N/R	2.49 5.04 6.07
SB FRS	576	291	298	6.01	2.95 UNMAN. 4.86 MAN.
SB PRS	634	320	954	6.54	4.04 UNMAN. 5.26 MAN.
EXPENDABLE W/AEROASSIST	497	278	775	5.51	3.43 UNMAN. 4.51 MAN.

MAJOR MCS COST DRIVERS ARE MISSION COMPLEXITY AND **MISSION DURATION**

MCS COST PER FLIGHT
 EXPENDABLES - LOWEST
 FULLY REUSABLE - NEXT LOWEST
 PARTIALLY REUSABLE - HIGHEST

 MCS COSTS ARE SIGNIFICANT BUT ARE NOT THE DISCRIMINATORS BETWEEN CONCEPTS "This page left intentionally blank"

8.0 LAUNCH AND RECOVERY IMPLICATIONS

This section presents a summary of the OTV launch and recovery impact as brought about by variations in the degree of OTV reusability, the Rev. 9 mission model, and use of an unmanned CLV.

8.1 LAUNCH MASS

A major factor in the cost comparison of the candidate OTV concepts is that associated with launch cost. The key contributor to this parameter is the mass that must be launched to accomplish the mission model. A comparison of the startburn weight to perform typical delivery and roundtrip missions is presented for the GB and SB OTV options as well as the total mass to accomplish the mission model.

Performance for the GB OTV's is shown in Figure 8.1-1. In the case of the delivery missions, the startburn weight involves the stage and a payload weight of 14.6K lbm. The indicated startburn weight difference also occurs for delivery missions involving payload weights as low as 10 K lbm. The expendable stage provides nearly 30 K lbm advantage over the fully or partially reusable concepts. This large margin occurs primarily because (1) no GEO deorbit delta V is necessary; (2) no aerobrake provisions are necessary; and (3) no configuration compromises are necessary to allow the stage or modules to be recovered including on-orbit loiter provisions and making the stage short enough to allow two to be returned in one STS flight as in the case of the FRS OTV concept. It should also be noted that over 80% of the missions in the model are delivery only. Round trip mission startburn weight however shows the FRS to have nearly a 40 K lbm margin over the expendable option. In this type of mission, the FRS is using aeroassist to return back into LEO whereas the expendable concept uses one stage to reach the mission orbit and another stage to return the payload to LEO via propulsive means. Use of an expendable stage to reach the mission orbit and an aeroassist module to return the payload only had nearly the same startburn weight as the FRS concept. The PRS concept was heavier than the FRS design primarily because two aerobrakes are involved (one for the P/A module and the other for the payload) and each of these brakes used a rigid TPS (due to heating rates) which is heavier than the ballute of the FRS concept.

SB OTV performance is presented in Figure 8.1-2 along with the GB FRS for relative comparison. In the case of the delivery mission of non-DoD payloads, the SB FRS requires the lowest startburn weight. The SB PRS is heavier primarily because its propellant tanks are launched loaded (or partially loaded if the mission dictates).

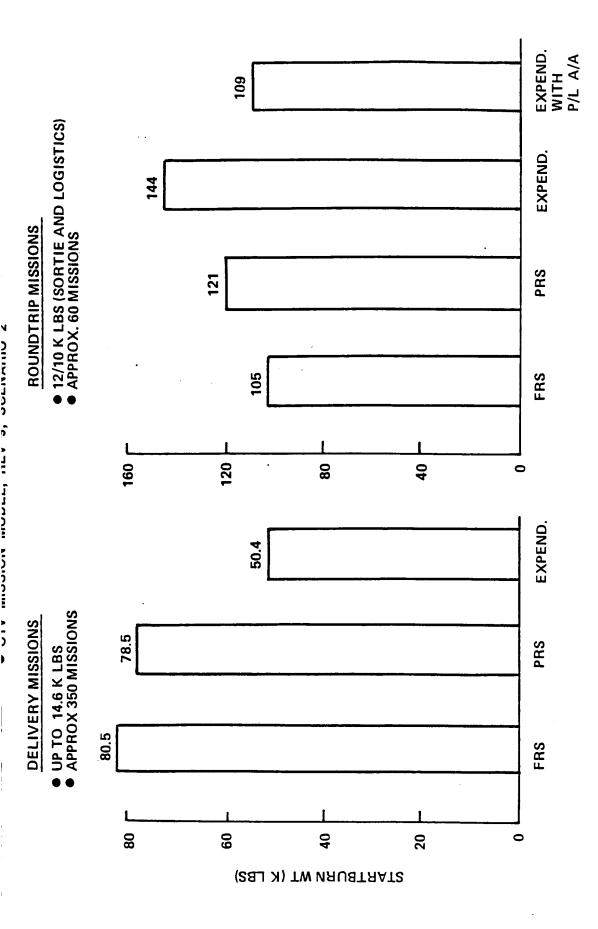


Figure 8.1-1. GB OTV Performance

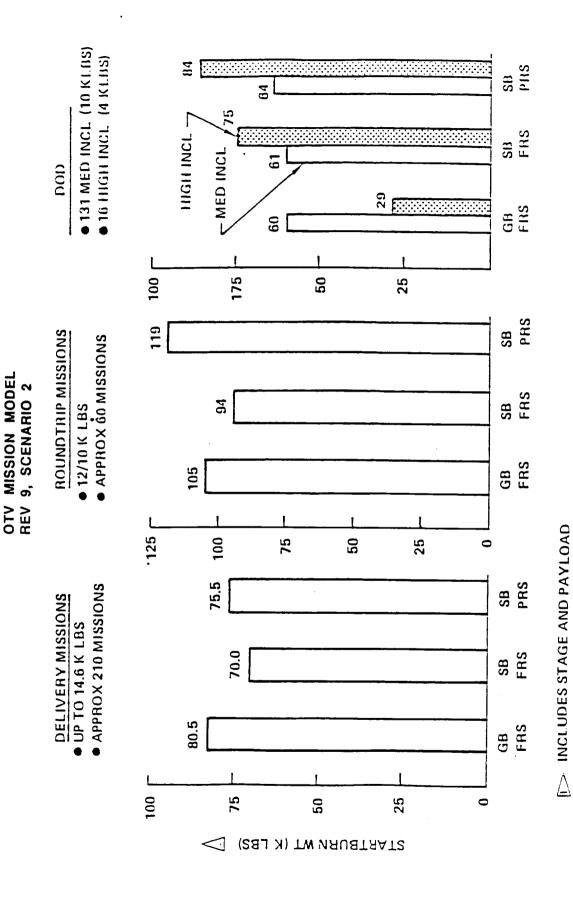


Figure 8.1-2. SB OTV Performance

Accordingly, the tanks are heavier than if designed only for mission loads as is the case for the SB FRS concept that uses a propellant tanker to deliver propellant from Earth to the Station's propellant storage tanks. The GB FRS is approximately 10 K lbm heavier than the SB FRS because (1) the tankage is designed for Earth launch and (2) a non-optimum (weightwise) tank design (toroidal LO₂) was necessary to make the stage short enough so two could be returned in one STS Orbiter. Roundtrip missions also involve less startburn weight when using the SB FRS. The SB PRS gets considerably heavier not only because of the tank design as discussed previously but also because two aerobrakes are involved as was discussed in the GB OTV performance paragraph.

DoD missions are all delivery type missions but a number of these involve medium or high inclinations. GB OTV's can be launched into or very near these inclinations whereas SB OTV's based at a $28\frac{1}{2}$ deg inclination Space Station must make a large plane change (Note: as discussed in Section 5.1, one station at $28\frac{1}{2}$ degrees was more cost effective than having two stations with the second at 63 degrees). In the case of the medium inclination synchronous missions, there is little difference between the three OTV options. Although the GB FRS requires much less plane change, the design penalty of toroidal tanks and on-orbit loiter capability both necessary to enable return of two stages in one Orbiter resulted in a startburn weight essentially the same as the SB FRS concept. The GB FRS shows a significant weight advantage for the high inclination 4000 nm orbit mission. This occurs because very little propellant is required to reach the altitude whereas the SB OTV options requires a plane change of over 60 degrees.

A comparison of the total launch mass associated with each OTV concept investigated in shown in Figure 8.1-3. The mass includes all stages, payloads, and propellant tankers required to perform the model. The expendable concepts show a significant advantage over the partial or fully reusable systems because the majority of missions are delivery only. For the average delivery mission, the expendable vehicle provides a 30K lbm and 20K lbm advantage over the reusable GB and SB OTV concepts, respectively. This advantage occurs because no propellant is required for GEO deorbit and no aerobrake is required for Earth orbit capture. On the relatively few large roundtrip missions, the GB reusable system has a 39K lbm advantage over the all-propulsive expendable concept and 4K lbm over the expendable with payload aeroassist. The reusable SB option has an even greater performance advantage over expendable options for the roundtrip missions.

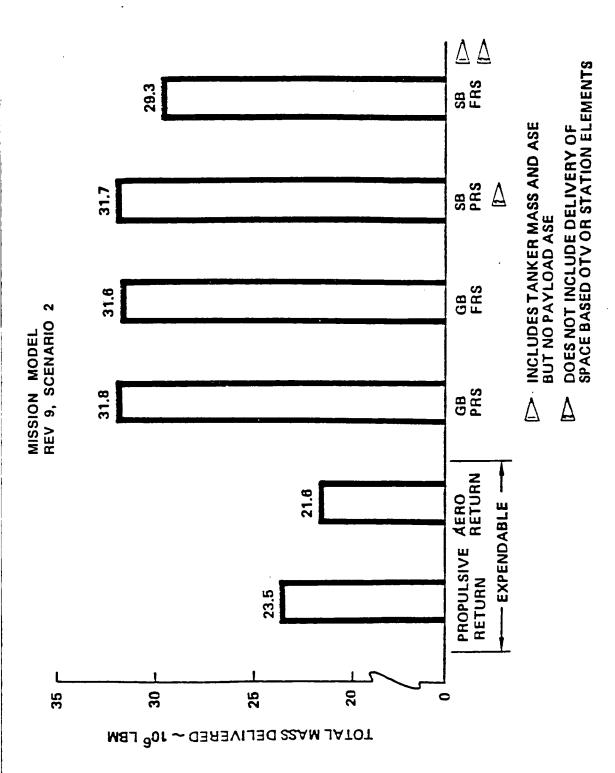


Figure 8.1-3. CLV Launch Mass Totals ('95 to '10)

8.2 RECOVERY OF OTV ELEMENTS

Both the reusable GB and SB OTV concepts have elements requiring Earth return. In the case of the GB OTV, the whole stage is involved while the SB OTV has a propellant delivery tanker that can be reused although its flight rate is only about one-third that of the GB OTV. Because the reference CLV does not have cargo return capability, other means must be used to return the reusable elements.

8.2.1 Recovery Options and Selection

The recovery options considered included: (1) add a reentry glider to the CLV; (2) use a 2 stage fully reusable CLV, and (3) STS/I/II flights that would take up delivery only cargo and then be available to return OTV elements.

The assessment of using a glider with the baseline partially reusable CLV to return hardware is summarized in Table 8.2-1. Specific design characteristics of such a concept were not available for this study. Instead we estimated a glider weight based on the ESA Hermes concept. When the glider was sized to return an empty OTV and a crew module (GEO manned sortic mission) a dry weight (no payload) of between 55K lbm and 60K lbm resulted leaving 90k lbm for the mission payload of the CLV. The launch requirement associated with the manned sortic mission is estimated at 105K lbm. Accordingly, this approach was judged to have insufficient CLV payload capability. In addition, the additional development cost for the glider would most likely exceed \$2 billion and the cost per flight for such a CLV/glider would also be higher than for a standard CLV.

A second option was to consider development of a fully reusable CLV. Such a concept was characterized in the Reference 7 study and provided 150K lbm LEO capability and cargo return capability in its Orbiter. The key features of this CLV approach relative to the partially reusable approach are shown in Figure 8.2-1. In summary, the large fully reusable CLV was found to have a higher LCC than a launch vehicle architecture that had a 150K lbm unmanned CLV and a 76K lbm fully reusable STS II. Accordingly, this approach was judged to be too costly.

The third option involved launching OTV elements on an unmanned CLV and have them returned to Earth via an STS that had delivered up only cargo. The basis for this approach is presented in Table 8.2-2. This approach was also used in the STAS study (Ref. 7). In that analysis, it was found the STS launches to inclinations where the majority of OTV flights would originate ($28\frac{1}{2}$ degrees) involved both delivery and return cargo and thus the STS would not be available for returning OTV elements. The means used to overcome this problem was to have the STS also launch up only cargo that would

ESA HERMES CONCEPT

DRY WT =

27,000

RETURN PAYLOAD =

10,000

• DDTE COST =

\$1 – 2 BILLION

SCALE UP TO 20K LBS RETURN PAYLOAD

SUITABLE FOR OTV AND 10K LB PAYLOAD

EST. DRY WT 55-60KLB

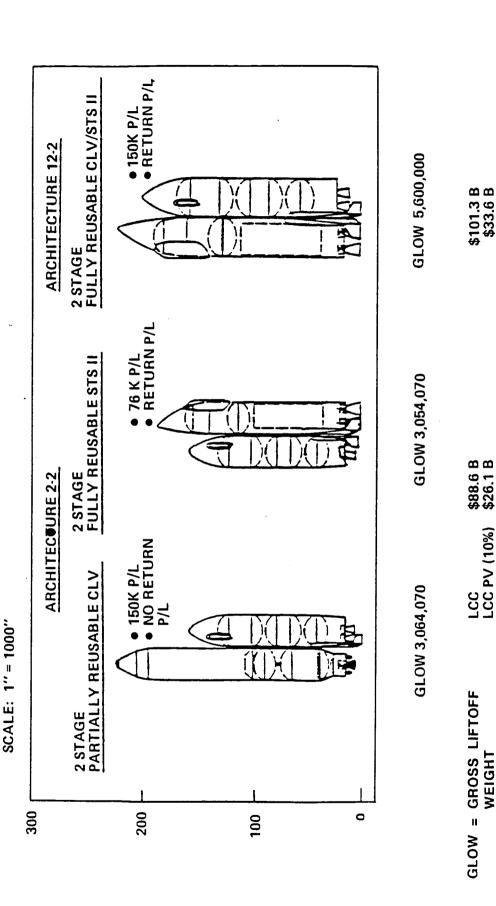
90K LB REMAINING CLV PAYLOAD

NOT ADEQUATE FOR OTV/10K LB ROUNDTRIP

PAYLOAD (105K LBS)

• DDTE COST > 2 BILLION

 CONCLUSION: ADDITIONAL DDTE, COST/FLIGHT AND REDUCED PAYLOAD MAKE CONCEPT NOT COST EFFECTIVE



CONCLUSION: 2 STAGE REUSABLE CLV NOT COST EFFECTIVE

= PRESENT VALUE

₽

Figure 8.2-1. CLV Comparison With and Without Payload Return

Table 8.2-2. Launch on CLV — Return via STS I/II

STAS ANALYSIS

- STS FLIGHTS TO 28½ DEG WERE ESSENTIALLY FULL BOTH ON **UP AND DOWN LEG**
- STS FLIGHTS TO OTHER ORBITS WERE NOT
- AVERAGE LOAD FACTOR WAS 0.7

OTV STUDY (SCENARIO 2)

- 275 FLIGHTS TO GEO VIA 28½ DEG
- 147 FLIGHTS TO 630 and 900

APPROACH

- LAUNCH ADDITIONAL STS FLIGHTS, WITH UP ONLY CARGO AND **RETURN OTV'S**
- EXTRA CARGO LAUNCHED REDUCES THE NUMBER OF REQUIRED CLV LAUNCHES FOR UP ONLY CARGO

normally be launched by a CLV. Although the launch of that particular cargo would be more expensive than if done by a CLV there was a residual benefit in as much as fewer CLV flights would be required for a given mission mode; and of course the OTV elements could be returned and reused. Accordingly this approach was selected to complete the OTV study because it had been successfully employed in the STAS study and the other return options had substantial cost and payload capability penalties.

8.2.2 Recovery Impact on Launches and Cost

Recovery of the GB FRS involves return of two small stages on each STS flight while only one of the large stages can be returned due to their size.

The launch impact for the GB FRS concept is summarized in Table 8.2-3. For this example, the number of CLV flights are reduced by having STS flights launch up only cargo normally launched by CLV's. With 24 small GB FRS stage flights, 12 STS flights are required and each large OTV (4 flights) required a separated STS for a total of 16 STS flights. The STS's up cargo capability resulted in reducing the number of CLV flights by 8. The launch impact in terms of delta STS and CLV flights associated with each of the investigated options is presented in Table 8.2-4. The GB partially reusable system (PRS) reflects the return of the propulsion/avionics module. The SB FRS concept involves return of the propellant delivery tanker. The expendable and SB PRS concepts have no return elements.

An example of the OTV recovery cost impact is shown in Table 8.2-5 using the GB FRS for illustrative purposes. The cost reflects the delta STS and CLV flights as well as the launch of ASE equipment on STS's that is necessary to allow return of the OTV elements. In the 1995 - 2001 time frame, the cost reflects use of the basic STS and results in an annual recovery cost impact of over \$700M. In the later time frame, STS II was defined by study groundrules to be available and with its cost per flight resulted in a savings of \$214M per year. Calculations similar to these were used for the other OTV concepts requiring recovery and are reflected in the cost of section 10.0.

Table 8.2-3. OTV Recovery Launch Impact Example, GBFRS

- 24 SMALL AND 4 LARGE GB FRS STAGES
- REQUIRES 16 STS FLIGHTS
- STS UP CARGO CAPACITY =

NO. FLIGHTS X AVG LOAD FACTOR X CAPACITY

16 X 0.7 X 65K = 728 KLBS*

AVERAGE LAUNCH CAPACITY OF CLV

AVG LOAD FACTOR X CAPACITY

 $0.6 \times 150 \text{ K} = 90 \text{ KLBS}$

CLV FLIGHT REDUCTION

 $\frac{\text{STS UP CARGO}}{\text{CLV CAPACITY}} = \frac{728}{90} = 8 \text{ FLIGHTS}$

* IGNORES OTV ASE GOING UP (FLYS IN 30% AVAILABLE SPACE)

Table 8.2-4 LAUNCH IMPACT (ANNUAL AVG)

						\bigcirc	
		GB <u>FRS</u>	GB <u>PRS</u>	EXPEND- ABLE	EXP W/ PL/ A/A	SB FRS	SB PRS
+ △ STS I/II FLTS	2	+16	+6	0	0	10.9	0
- △ CLV FLTS	3	-8	-3	0	0	5.6	0

PROPELLANT TANKER

WITH LOAD FACTOR OF 0.7

WITH LOAD FACTOR OF 0.6

SELECTED CONCEPT

Table 8.2-5. OTV Recovery Cost Impact Example

• COST IMPACT =

COST OF △ STS FLIGHTS

PLUS

LAUNCH OF RETURN ASE FOR OTV'S

SUNIM

COST OF FEWER CLV FLIGHTS

• 1995—2001 (STS I)

ADDITIONAL STS FLIGHTS

4 K 49 K × 16 × \$73M 16 × \$73 M

+ 95M

+ \$1168M

11

- 560 M

-8× \$70 M

+\$703M/YR NET

+ \$320M

11

16 × \$ 20M

+ \$26M

2002-2010 (STS II) [>>

FEWER CLV FLIGHTS

LAUNCH ASE

 ADDITIONAL STS II FLIGHTS LAUNCH ASE

4/49 x 16 x 20 -8× \$70 M

-560M -\$214M

FEWER CLV FLIGHTS

ASSUMES SAME AVERAGE LOAD FACTOR → 49K LBS IS FULL LOAD POINT

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9.0 OTV CONCEPT SELECTION TRADES

This section presents a summary of the data used to determine the recommended OTV program associated with the Phase II groundrules. The data is presented in a sequence that defines the best GB OTV concept, the best SB OTV concept and finally a comparison of these winners to determine the preferred OTV for the baseline analysis of the Rev. 9, Scenario 2 mission model. Prior to making the overall assessment of the options consideration is also given to sensitivities involving Scenario 2 and findings associated with mission model scenarios 1 and 5.

9.1 GROUND BASED OTV SELECTION TRADE

Three major ground based (GB) OTV concepts are evaluated. These include a reusable system, partially reusable system, and expendable system with the latter having two options. Each concept involves a delivery mission configuration and a roundtrip mission configuration.

The delivery mission configurations are compared in figure 9.1-1. All concepts use L02/LH2 propellant and two advanced space engines as a result of the main propulsion and cost optimum redundancy trades performed in Phase I. The concept defined as a fully reusable system (FRS) has been designed to allow two of these vehicles to be returned in the cargo bay of STS I or II and thus minimize the impact of its launch vehicle (the CLV) not having cargo return capability. The principal features to allow this include a toroidal LO2 tank and a LH2 tank with 0.5 heads. In addition, on-orbit dormancy or loiter provisions were also incorporated to enable the vehicle to remain flight worthy while awaiting pickup by a STS. Although these design features make for a relatively short stage they have a significant mass penalty resulting in a propellant requirement of 56K lbm. A ballute is used for the aeromaneuver and is expendable. The partially reusable system (PRS) has an operating mode that only recovers the high value propulsion and avionics elements. The low value propellant tank is expended to reduce the impact relative to Earth return. The recovered systems are located within a propulsion/avionics (P/A) module that also employs a rigid ablative aerobrake used in the LEO aeromaneuver. The tankset provides the necessary propellant through the GEO deorbit burn at which time it is placed on an atmosphere impact trajectory. The P/A module continues toward LEO where the aeromaneuver is performed with circularization provided by a small storable propulsion system. The additional benefit of this concept is that the recovered P/A module is short enough that five can be returned to Earth in one Orbiter. A new expendable OTV concept requires significantly less

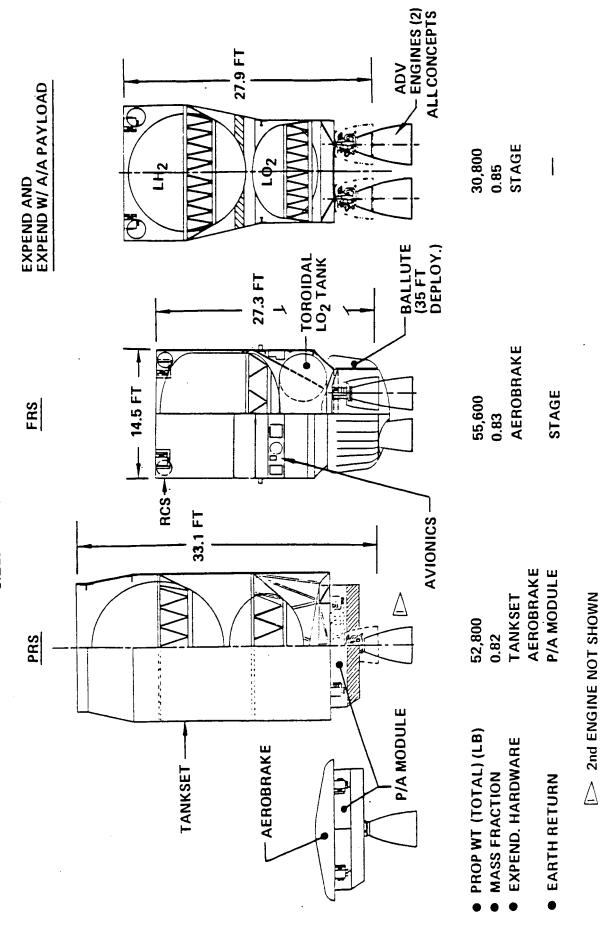


Figure 9.1-1 GB OTV Concepts - Delivery Mission Configuration

propellant than the other concepts because its mission essentially ends with payload deployment at GEO. A small burn does occur however after deployment with the purpose being to place the stage in a disposal orbit approximately 900 nmi above GEO. Advanced high performance engines are used on this concept to stay within the payload capability of the launch vehicle when performing the manned GEO sortic mission.

The roundtrip mission configurations for the GB FRS and PRS concepts are shown in figure 9.1-2. The sizing mission is the manned GEO sortie involving 12 K lb (out)/10 K lbm (return). This mission requires considerably more propellant than the delivery mission and accordingly the vehicle size precludes more than one being returned per Orbiter. Accordingly, 0.7 tank heads are used to provide better structural efficiency. The vehicle returns to the Space Station immediately after the manned mission and thus no dormancy provisions are included. The GB PRS also has several changes. A larger tankset is required and a separate aerobrake module is attached to the crew module. The operating mode for this concept is similar to the delivery mission configuration but with the additional feature that after the GEO deorbit burn the first element to separate is the crew module and its aerobrake module. The aerobrake module contains a storable propulsion system, a flexible TPS aerobrake, and avionics to enable the aeromaneuver back into LEO. Primarily because two aerobrake modules are required by the PRS, the propellant loading is considerably higher than for the FRS concept.

Roundtrip configurations for the expendable OTV concept are shown in figure 9.1-3. Two options are available to perform the more demanding roundtrip manned GEO sortie mission. An all-propulsive mode employs two larger stages. Both are expended following propellant depletion (although the second stage could be returned to earth if its diameter were changed to be STS cargo bay compatible). The second approach would use a single large stage (even larger than the all-propulsive mode) and an aeroassist module to return only the payload. The stage in this case provides the delta-V capability through deorbit from GEO at which time the aeroassist module with its payload separates for return to LEO. The aeroassist device for this concept provides an L/D of 0.1 and uses rigid ablative thermal protection. As will be noted in the comparison of the propellant weight, a considerable advantage exists for the aeroassisted concept relative to the all propulsive concept.

The LCC summary comparison for the candidate GB OTV concepts is presented in figure 9.1-4. Both expendable OTV options provide a significant advantage for both undiscounted and discounted costing. The cost breakdown of the nonrecurring, production, and recurring costs are shown in table 9.1-1. The expendable option

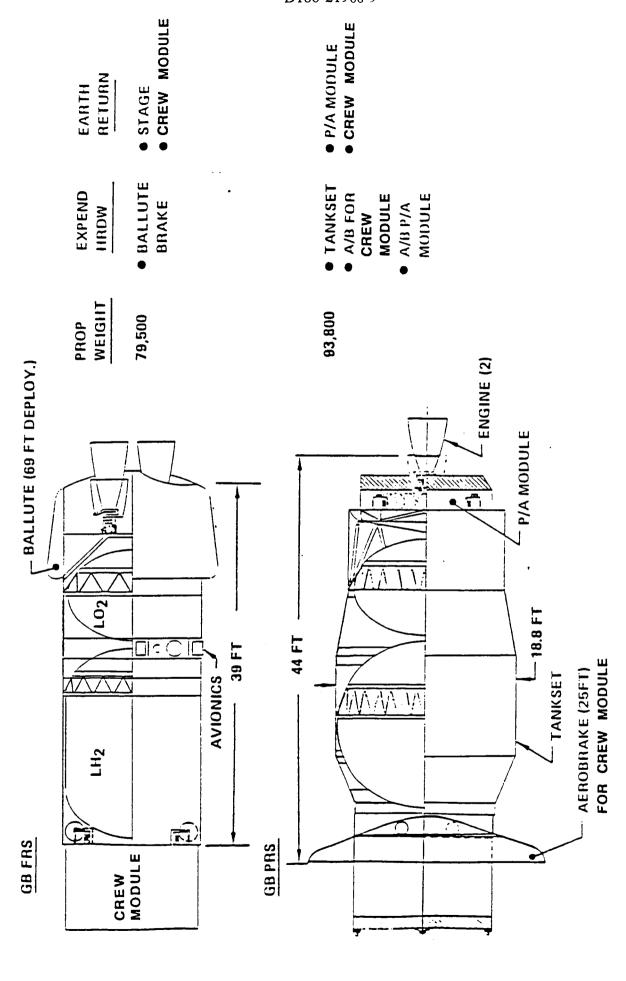


Figure 9.1-2 GB OTV Concepts - Roundtrip Mission

● CREW MODULE

BOTH STAGES

• 117,300 TOTAL

EARTH RETURN

EXPEND HRDW

WEIGHT

PROP.

EXPENDABLE- 2 STAGE (ALL PROPULSIVE)

- 16.3 FT DIA

CREW MODULE LH₂

Figure 9.1-3 GB OTV Concept - Roundtrip Configuration

OTV-1426

65 FT

UNDISCOUNTED

DISCOUNTED (10%)

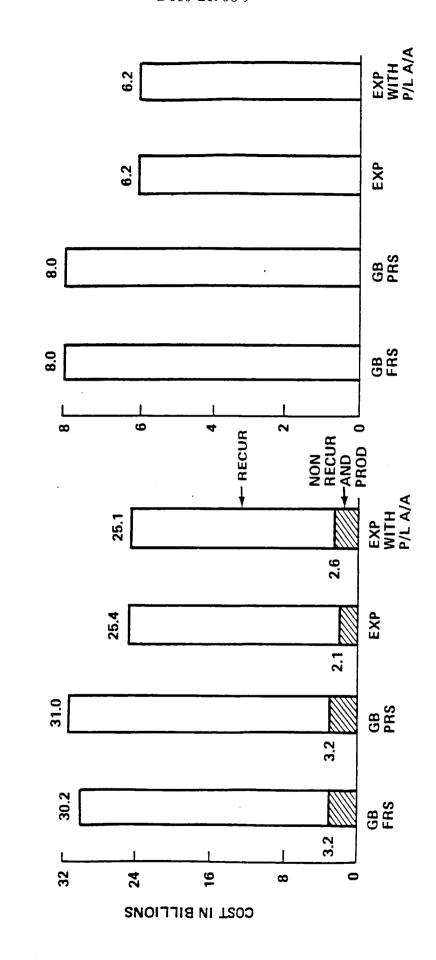


Figure 9.1-4. GB OTV Program LCC.—Phase II

A/A = AEROASSIST

Table 9.1-1 GB OTV LCC Breakdown — Phase II (Scenario 2)

	GB FRS	GB PRS	EXP.	EXP. W/
				P/L A/A
NON-RECURRING	(2,620)	(2,751)	(2,091)	(2,557)
• OTV	1,657	1,701	1,348	1,662
MISSION CONTROL SYS.	867	964	623	775
GROUND OPERATIONS	96	96	120	120
PRODUCTION	(573)	(432)	(0)	(39)
SMALL VEHICLE	495	ı	1	1
LARGE VEHICLE	78	1	1	1
• P/A MODULE	. 1	404	1	1
• P/L MODULE	I	28	ı	39
RECURRING	(27,068)	(27,773)	(23,308)	(22,521)
· LAUNCH (USING CLV)	20,023	19,902	13,976	13,667
MISSION CONTROL	1,743	2,188	1,473	1,601
OTV PROCESSING	640	683	1,153	1,174
 EXPEND./AMORT. HARDWARE 	418	3,570	902'9	5,946
DOWN—CARGO IMPACT	4,242	1,429	0	132
• TCC	30,261	30,955	25,399	25,117
DISCOUNTED	8,038	8,029	6,237	6,248

provides the least nonrecurring cost because it uses the smallest vehicle and has the simplest flight operations. Production costs for the expendable options are for the most part shown as expendable hardware under recurring. Within the recurring cost both expendable options show a significant advantage primarily because their savings in launch cost (less mass) and down cargo cost more than offset their higher expendable hardware cost. The FRS has the greatest down cargo cost because 16 STS flights per year are required to return the stages, which does eliminate an equivalent of 8 CLV launches (see section 8.0), but still results in a \$4200 million penalty.

Based on the above cost comparison both expendable options should receive further consideration.

9.2 SPACE BASED OTV SELECTION TRADE

The space based (SB) OTV candidates include a fully reusable system (FRS) and partially reusable system (PRS). Again, both concepts utilize two configurations with one sized by the 14.6K lbm delivery mission and the other by the manned GEO sortic mission. The SB FRS configurations are shown in figure 9.2-1 along with the GB FRS configurations to assist in understanding their differences. The SB concept uses 0.7 head tanks, comes directly back to the Station so no loiter provisions are necessary and, in addition, has tanks sized for mission loads rather than launch loads. All of these factors contribute to the SB FRS requiring 9K lbm less propellant for this mission class relative to the GB FRS. The SB OTV concept however does require orbital supporting elements that are not necessary for the GB options. These include hangars with maintenance and servicing equipment and propellant storage systems at a Space Station and a propellant delivery system to supply the propellant storage tanks at the Station. The features of these orbital support elements were summarized in Section 5.0.

The SB PRS configurations are shown in figure 9.2-2. The overall design features and mission operations were essentially the same as for the GB PRS concept. There are, however, several key differences. The P/A module and roundtrip payloads will remain on-orbit at the Space Station following a mission. Prior to each subsequent delivery mission, a new tankset and aerobrake for the P/A module requires launching to the Station where they can be attached to the P/A module. Although this approach eliminates any down cargo need (e.g., propellant tanker in the case of the SB FRS concept), it does result in a tankset designed for launch vehicle loads rather than OTV mission loads and thus the performance is not as good. In the case of a roundtrip mission, the launch needs also include an aerobrake module for the roundtrip payload. For this mission type, the SB PRS concept requires over 20K lbm more propellant than

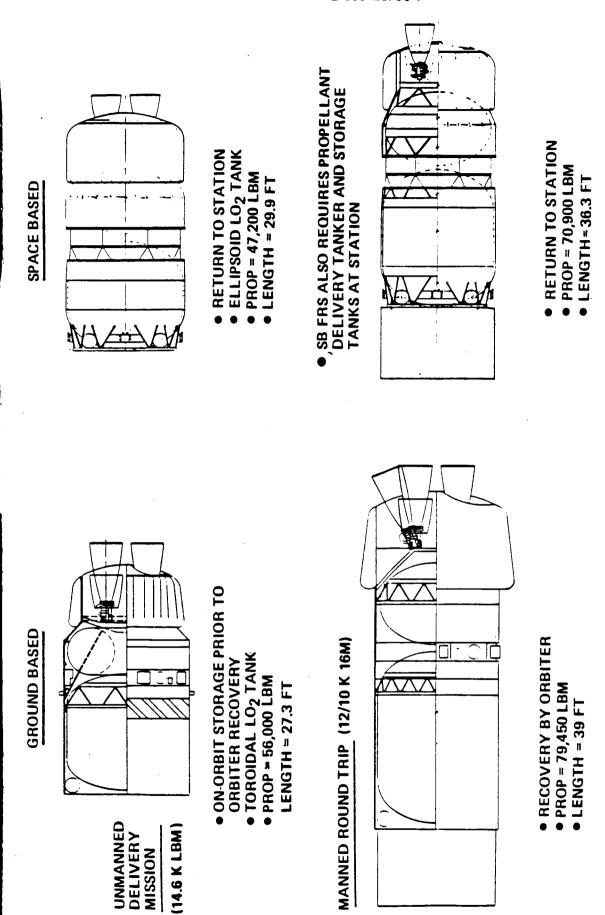


Figure 9.2-1 GB and SB FRS Comparison

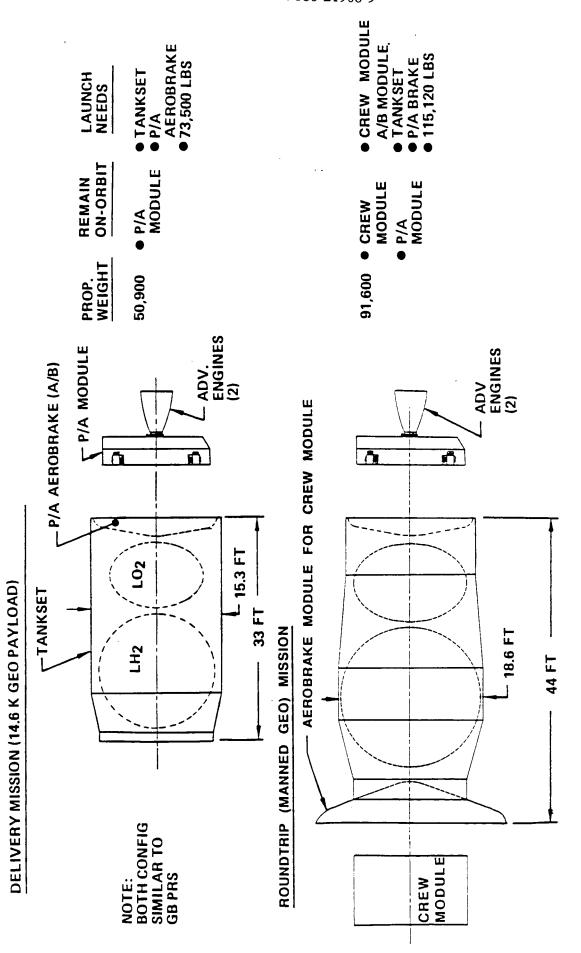


Figure 9.2-2 SB PRS Configuration

the SB FRS concept. The SB PRS concept however does eliminate the cost associated with propellant tankers and storage tanks at the Station, can use a smaller hangar, and requires less on-orbit preparation time relative to the SB FRS concept.

The LCC summary comparison is shown in figure 9.2-3 with the breakdown provided in table 9.2-1. Also included in these comparisons is the GB FRS to show key cost differences. Relative to the two SB options, the FRS concept provides a 15% advantage over the PRS in undiscounted cost and an 8% advantage when discounted. The SB FRS has a higher nonrecurring and production cost because of its orbital support needs (Station accommodations/operations and propellant tanker). The most significant difference in recurring cost is that associated with launch. The FRS has a large advantage because the launch mass of the PRS options is more like that of a GB OTV due to its tankset design.

9.3 OTV PROGRAM SELECTION TRADES

Selection of a preferred program includes consideration of the Scenario 2 results, sensitivities, and results from other scenarios.

9.3.1 Scenario 2 Baseline Comparison

The leading contenders from the individual GB and SB OTV comparisons included the expendable and expendable with aeroassist payload return, a GB FRS, and SB FRS concepts. Programmatic characteristics of the four OTV options are shown in figure 9.3-1. Each option is defined in terms of the type of vehicle and number of flights that are involved (i.e. small stage, 2 stage, man-rated) to satisfy the key missions occurring throughout the model. For example, in the GB FRS concept, 352 flights require the small stage and 9 flights require a 2 stage vehicle using small stages. Use of the large GB FRS stage involves 39 flights using a single stage, 4 flights using 2 stages, and 16 flights requiring a man-rated stage.

The life cycle cost summary comparison for the four primary concepts is presented in figure 9.3-2. It will be noted that the two expendable concepts provide the least LCC with the reusable GB or SB OTV's being 20% higher without discounting and 28% higher with discounting. The LCC breakdown is shown in table 9.3-1. The all expendable concept has the lowest non-recurring and production costs because it is the smallest vehicle; the SB OTV has the highest due to the orbital support elements. Production cost for the expendables is collected as expendable hardware under recurring cost. Several categories under recurring contribute to the significant cost advantage of the expendables. In the area of launch cost which used a Shuttle type users charge policy,

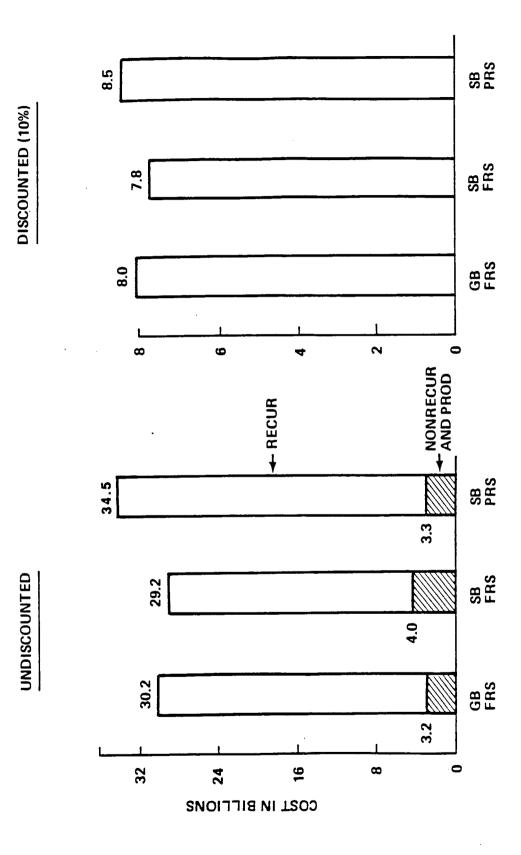


Figure 9.2-3 SB vs. GB OTV Program LCC - Phase II

Table 9.2-1 SB OTV LCC Comparison — Phase II (Scenario 2)

	GB FRS	SB FRS	SB PRS
NON-RECURRING	(2,620)	(3,260)	(2,978)
• OTO •	1,657	1,560	1,800
MISSION CONTROL SYS.	867	867	954
 GROUND OPERATIONS 	96	38	95
ORBITAL SUPPORT	1	795	153
PRODUCTION	(573)	(735)	(322)
SMALL VEHICLE	495	350	1
LARGE VEHICLE	78	69	1
• P/A AND P/L MODULES	l	i	272
ORBITAL SUPPORT	1	316	50
RECURRING	(27,068)	(25,206)	(31,228)
LAUNCH (USING CLV)	20,023	15,991	20,379
MISSION CONTROL	1,743	1,603	2,049
OTV PROCESSING	640	4,060	3,979
 EXPEND./AMORT. HARDWARE 	418	1,389	4,414
ORBITAL SUPPORT	1	1,085	406
DOWN-CARGO IMPACT	4,242	1,077	0
• רככ	30,261	29,202	34,548
DISCOUNTED	8,038	7,812	8,510

Figure 9.3-1 OTV Program Options

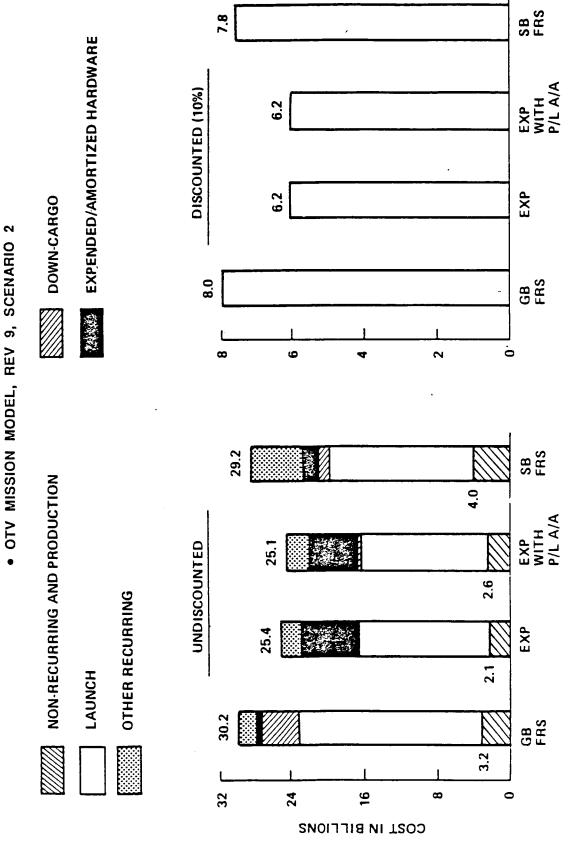


Figure 9.3-2. OTV Program LCC—Phase II

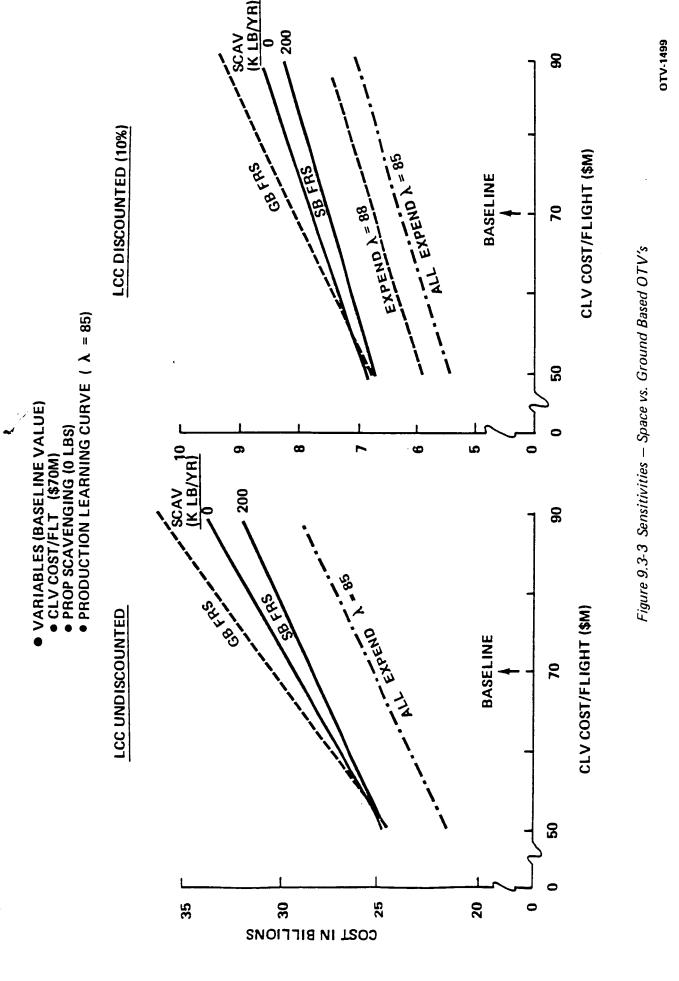
	GB FRS	EXP.	EXP. W/	SB FRS
			P/L A/A	
NON—RECURRING	(2,620)	(2,091)	(2,557)	(3,260)
• OTV	1,657	1,348	1,662	1,560
MISSION CONTROL SYS.	867	623	775	867
GROUND OPERATIONS	96	120	120	38
ORBITAL SUPPORT	1	l	i	795
PRODUCTION	(573)	<u> </u>	(39)	(735)
SMALL VEHICLE	495	1	ı	350
LARGE VEHICLE	78	1	1	69
 P/A AND P/L MODULES 	ı	1	39	ı
ORBITAL SUPPORT	1	I	l	316
RECURRING	(27,068)	(23,308)	(22,521)	(25,206)
LAUNCH (USING CLV)	20,023	13,976	13,667	15,991
MISSION CONTROL	1,743	1,473	1,601	1,603
OTV PROCESSING	640	1,153	1,174	4,060
 EXPEND./AMORT. HARDWARE 	418	6,706	5,946	1,389
ORBITAL SUPPORT	1	I	l	1,085
DOWN-CARGO IMPACT	4,242	0	132	1,077
• FCC	30,261	25,399	25,117	29,202
DISCOUNTED	8,038	6,237	6,248	7,812

the advantage is due to the significantly less mass that must be launched. An advantage also occurs over the SB in the area of OTV processing due to the latter's high cost per crew hour on-orbit as well as a savings in the down cargo impact as this parameter reflects the return of the propellant tanker for the SB OTV. The down cargo impact was also a major advantage of the expendable over the GB FRS because all of its stages had to be returned. The one area of significant cost penalty associated with the expendable concept is that of expendable hardware. The expendable stages used an average theoretical first unit (TFU) cost of \$49M and a production learning curve of 85%. The expendable option that used aeroassist for roundtrip payload return had essentially the same LCC because its lower recurring (less expendable hardware) offset its higher non-recurring cost.

9.3.2 Sensitivities

Several sensitivities within Scenario 2 were also considered. The results of three sensitivities dealing with CLV cost per flight, propellant scavenging and production learning are shown in figure 9.3-3. Over the range of the values evaluated, the expendable system still provided the lowest discounted cost. A switch in relative standing did occur between the GB and SB FRS concepts when the CLV cost was reduced to \$50 million per flight. (note: this was the CLV cost value in the Boeing STAS study). Production learning in the baseline analysis assumed a 90% curve for low rates (i.e. reusable systems - 2 per year) and 85 for high rates (i.e. expendable OTV - 20 per year). Increasing the high rate production learning to 88 still resulted in the expendable being the least cost. Propellant scavenging was not included in the baseline analysis but it appears the value would have to exceed 700K lbm per year before the SB OTV options match the expendable option with a production learning value of 88.

Another variation suggested near the end of the study was the concept of propellant hitchhiking. This concept involved manifesting OTV propellant tankers on CLV flights delivering payloads but not using the full launch capability. In addition, there was the assumption that the transportation cost for the propellant would be free. Analysis of mission models similar to Rev. 9 scenario 2 has indicated an average of only three flights per year to 28 1/2 degree orbits which would contribute approximately 200K lbm of the annual 1300 K lbm requirement. Assuming this propellant is delivered free there would be a net savings of \$1.5B but still the discounted LCC for the SB OTV would be 19% higher than that for the new expendable OTV mode. In summary, if the purpose of the system level studies is to determine what should be done, then all hardware and operations cost associated with the concepts must be included in the decision process.



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Accordingly, the hitchhiking cost premise appears invalid because all elements are not being included. Furthermore, even if implemented, the SB OTV concept still is not as cost effective as the expendable OTV concept.

9.3.3 Results in other Mission Scenarios

Four other scenarios were associated with the Rev. 9 mission model. Scenario 1 reduced the OTV flights from 422 to 292 and Scenario 3 was essentially the same as 1. Scenarios 4 increased the flights to 667 but the major contribution to the higher number of missions was high inclination delivery type DOD missions where the expendable performed better than the other concepts and thus no change would be expected in the LCC comparison. Scenario 5 involved 872 missions and several new mission categories. Of most interest was Scenario 1 to determine the impact on the program/basing issue and Scenario 5 because of the strong focus on a manned lunar exploration program. The results are summarized in the following paragraphs.

The sizing missions for Scenario 1 are shown in figure 9.3-4. Very significant in this model is the fact that there are no roundtrip missions. The majority of the delivery missions can be accomplished with a propellant load of < 56K lbm assuming a reusable GB OTV. There are two flights that would require more propellant, however these could be accomplished using a two stage vehicle. Because there were no roundtrips and the majority of the delivery missions were < 14.6K lbm payload only the small stages for the GB FRS, SB FRS, and expendable concepts were evaluated. The LCC comparison for the concepts performing Scenario 1 is presented in table 9.3-2. In this Scenario, the all propulsive expendable concept has even a larger cost savings (over 40%) compared to the GB and SB FRS concepts. The primary reason is because there are no large delivery or roundtrip missions and thus the launch cost savings percentage is even greater than for Scenario 2.

Scenario 5 nearly doubled the number of OTV flights relative to Scenario 2. The percentage of roundtrip and large delivery mission were essentially the same however and consequently there should not be any change between the concepts in terms of LCC relationships. Accordingly, the expendable concepts would still look most favorable as long as the primary launch system was an unmanned cargo launch vehicle without cargo return capability.

Consideration was given however to the accomplishment of the two new mission categories namely nuclear waste disposal (NWD) and lunar surface exploration. In the case of NWD there were 391 missions involving a 10K lbm payload to a 0.7 A.U. disposal orbit. Analysis indicated this mission could be accomplished using the small expendable

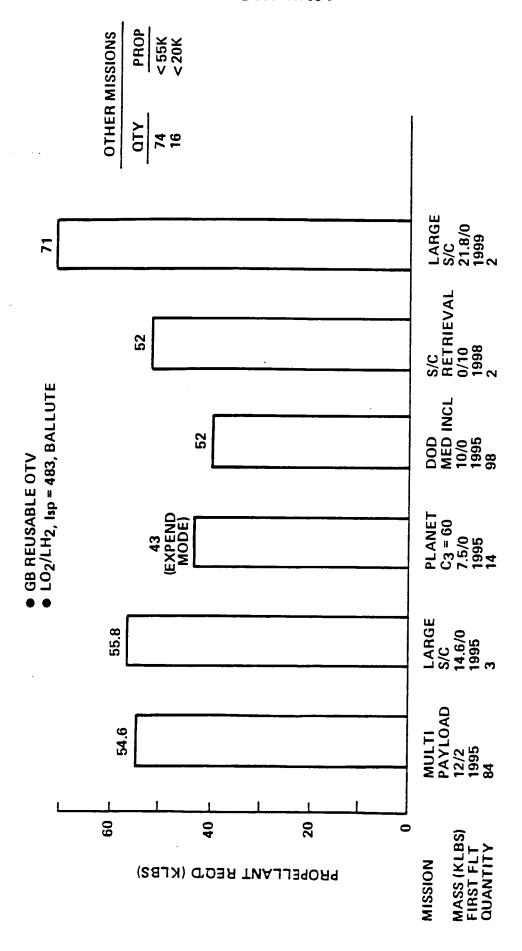


Figure 9.3-4 Scenario 1 Sizing Missions

Table 9.3-2 OTV LCC Comparison – Phase II (Scenario 1)

	GB FRS	EXP.	SB FRS
NON-RECURRING	(2,077)	(1,469)	(2,665)
VIO •	1,130	750	1,065
MISSION CONTROL SYS.	867	623	867
GROUND OPERATIONS	80	96	38
ORBITAL SUPPORT	1	I	695
PRODUCTION	(300)	(0)	(402)
SMALL VEHICLE	300		267
LARGE VEHICLE	ı		
• P/A AND P/L MODULES	1	1	1
ORBITAL SUPPORT		1	138
RECURRING	(17,717)	(13,717)	(18,580)
· • LAUNCH (USING CLV)	12,764	7,809	12,293
MISSION CONTROL	1,235	928	1,132
OTV PROCESSING	440	791	2,788
EXPEND./AMORT. HARDWARE	287	4,189	1,076
ORBITAL SUPPORT	. 1	I	718
DOWN-CARGO IMPACT	2,991	0	474
• LCC	20,094	15,186	21,650
DISCOUNTED	6,055	4,239	6,266

OTV with 30K lbm propellant capacity. This mission involved two perigee burns for transfer out to the 0.7 A.U. orbit, 160 days of coast and a burn into the disposal orbit.

Accomplishment of the lunar exploration program using the expendable OTV concept is shown in figure 9.3-5. This approach assumes an OTV concept that involves an expendable mode along with aeroassist payload return. The early unmanned lunar mission can be done with the small expendable stage that was sized for the 14.6K lbm GEO delivery mission. To perform the unmanned surface exploration mission a new stage would be used that is sized by the manned surface sortie mission. Such a stage would have 95K lbm propellant capacity. This same size stage would be used for the GEO logistics and manned sortie missions which required 80K lbm of propellant. The manned lunar surface sortie mission would use two of the large stages and an aerobrake module to return the manned module to LEO. The first stage provides the delta V for lunar transfer. The second stage injects the payload into lunar orbit and provides the earth return transfer delta V. The aerobrake module provides the means to circularize into earth orbit. Placement of a station into lunar orbit to assist in the surface explorations would also be done by two of the large stages.

9.3.4 Overall Assessment and Recommendation

The recommendation at this time for the groundrules of Phase II is that a program should begin with a new technology cryogenic expendable OTV sized for 15K lbm GEO delivery capability. As more demanding missions materialize, two options are available. One is to continue in an all-propulsive mode and use two stages. The other option, particularly if there is a significant number of roundtrip missions, would be to develop a new size expendable stage and also an aeroassist module that could be used to return the roundtrip payloads. This approach has been shown to be the cost optimum for Scenario 1 and 2. In addition, it is projected that this approach would also offer the least cost for the other Scenarios in Rev. 9 because either they involve missions more favorable to the expendable mode and/or have the same percentage of roundtrip mission or large delivery missions as Scenario 2. More ambitious missions such as nuclear waste disposal or manned lunar exploration can also be done effectively. In summary, the recommended new technology expendable OTV program provides significant cost advantages, has good growth capability, and best utilizes the capabilities of a mixed launch fleet.

LUNAR MISSION

- **UNMANNED ORBITER**
 - 5.1/0 K LBS
 - **1996**

REQ'D Wp= 14.9K LBS

STAGE CHARACTERISTICS

- CAPACITY = 30.5 KLBS

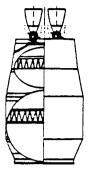
 - STAGE USED ON ALL GEO DELIV MISSIONS OF ≤ 14.6 K LBS
- REQ'D Wp = 60K LBS

UNMANNED SURFACE EXPLORATION

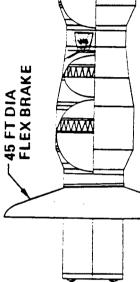
32.8/0 K LBS

▶ 2000

• CAPACITY = 95K LBS







REQ'D Wp = 187 K LBS



• REQTD Wp = 156 K LB

- 72.6/20 (L.O./RETURN)K LBS **■ MANNED SURFACE SORTIE**

LUNAR ORBIT STATION

93/0 K LBS2008

Figure 9.3-5 Lunar Exploration — Scenario 5 (Expendable OTV Program)

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10.0 SUPPORTING COST DATA

This section presents additional cost data beyond the summaries reported in section 9.0.

10.1 GENERAL GROUNDRULES AND ASSUMPTIONS

The groundrules and assumptions that apply to all OTV concepts investigated during Phase II are presented in table 10.1-1. It is important to note that all DDT&E cost include one flight (operational) unit and one GSE unit. The test hardware assumed for the DDT&E effort is shown in table 10.1-2. A key factor in this area is that the first flight article will initially serve as the functional test article. Following the functional test, the unit is refurbed and used as a flight unit.

10.2 FULLY REUSABLE OTV'S

The costs associated with the GB and SB fully reusable system (FRS) concepts are presented. Both of these concepts used three vehicle types as shown in figure 10.2-1 to satisfy the mission model. The GB and SB FRS concepts were described in section 3.3 and 3.7, respectively.

10.2.1 Unique Groundrules and Assumptions

In addition to the general groundrules that applied to all OTV concepts, each concept also involved some unique groundrules. For the most part, these groundrules defined relationships between the different vehicles of a given concept. As will be noted, the majority deal with the assumed degree of commonality. Those that apply and are common to the GB and SB FRS concepts are presented in table 10.2-1.

10.2.2 GB FRS OTV Concept Cost

10.2.2.1 Cost Summary

The total cost for the GB FRS concept both undiscounted and discounted is presented in table 10.2-2. Further discussion of the cost associated with each system element is provided in subsequent paragraphs.

Table 10.1-1. Costing Groundrules and Assumptions – Phase II

ALL COSTS REPORTED IN CONSTANT FY 1986 DOLLARS WITH NO FEES OR CONTINGENCIES ADDED.

LIFE CYCLE COSTS ARE REPORTED BOTH UNDISCOUNTED AND DISCOUNTED AT 10% PER YEAR STARTING IN 1985 AS YEAR 1.

RESEARCH AND DEVELOPMENT (TECHNOLOGY) COSTS ARE INCLUDED AS TRADES DISCRIMINATORS, BUT ARE NOT INCLUDED IN THE PROGRAM LIFE CYCLE COSTS.

THE REVISION 9 MISSION MODEL WAS USED FOR OPERATIONS COSTING.

ENGINE DEVELOPMENT AND PER UNIT COSTS ARE CONSISTENT WITH DON SAXTON'S REVISED GROUNDRULES DATED MAY, 1985.

OPERATIONS COSTS, SUCH AS ANY USER CHARGES, EVA/IVA, GROUND MISSION OPERATIONS, AND PROPELLANT SCAVENGING ARE CONSISTENT WITH DON SAXTON'S REVISED GROUND RULES.

THE USABLE LIFETIME OF THE ENGINES AND VEHICLE COMPONENTS WERE ASSUMED TO BE AS FOLLOWS:

300 FIRINGS 1 FLIGHT ADV. SPACE ENG. BALLUTE **40 FLIGHTS 40 FLIGHTS 5 FLIGHTS LIFTING BRAKE** STRUCTURE AVIONICS

▶ LAUNCH VEHICLE COST PER FLIGHT BASED ON STUDY GROUNDRULES

STS COST PER FLIGHT: \$73M

STS II COST PER FLIGHT: \$20M

CARGO LAUNCH VEHICLE COST PER FLIGHT: \$70M

- SPARES COST BASED ON 10% OF HARDWARE.
- STS FLIGHT HARDWARE AND FACILITIES ENHANCEMENT COSTS, AS WELL AS SCAVENGING SYSTEMS DEVELOPMENT COSTS, ARE PER THE DON SAXTON REVISED GROUND RULES.
- HARDWARE DEVELOPMENT SCHEDULES WERE ASSUMED AS FOLLOWS:

	EXPENDABLE ALIXILLARY TANKS 3 YEARS	SEE SOVILIANT TANKS 3 YEARS	
RELISABLE	EXPENDAG		
5 YEARS	4 YEARS	6 YEARS	6 YEARS
NEW VEHICLE	MODIFIED VEHICLE	ADV. SPACE ENG.	ADV. GROUND ENG.

- TEST HARDWARE QUANTITIES ARE DISPLAYED IN TABLE 10.1.
- ONE FLIGHT UNIT AND SET OF GROUND SUPPORT EQUIPMENT ARE INCLUDED IN DD&E.
 - A LEARNING FACTOR OF 90% ON REUSABLE AND 85% ON EXPENDABLE HARDWARE.
 - PROPELLANT SCAVENGING USING CARGO BAY CONCEPT @ 200,000 LB

	•							ט	100-2190	0-9			
	TOTAL	2 1/4		-	, c	7 C	7 (2 21,6	2/2 IIVE				
	FLT TA	-	· -	· -	• -				E RESPECT				
TEST ARTICLE-QUANTITY	SIL				· -	•.			DED IN THOS	THE STA	CTURE ONLY		
T ARTICLE	MPTA	1/4 [3]	1						ING INCLU	USED FOR .	RUST STRU		ARTICLE
TES	FTA	\triangle	ı			(-	-	1/2/4	OWER COOL	DWARE AS	RE AND THI	10	ONAL TEST
	STA	-	Δ			-			ONICS & P	SAME HAR	STRUCTUI	N ENGINES	AS FUNCTION
	SUBSYSTEM	STRUCTURE	THERMAL CONTROL	ELEC. POWER	AVIONICS	AEROASSIST/HEAT PROT	RCS	MAIN PROPULSION	EXCLUDES AVIONICS & POWER COOLING INCLUDED IN THOSE RESPECTIVE SUBSYSTEMS	UTILIZES THE SAME HARDWARE AS USED FOR THE STA	(3>) INCLUDES AFT STRUCTURE AND THRUST STRUCTURE ONLY	EXCLUDES MAIN ENGINES	S ALSO SERVES AS FUNCTIONAL TEST ARTICLE

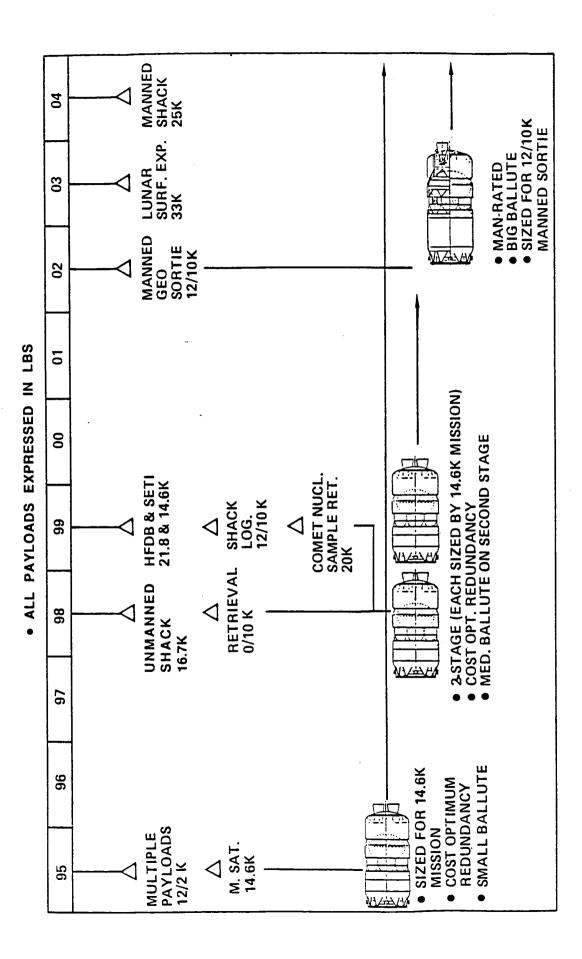


Figure 10.2-1. FRS OTV Mission Application

Table 10.2-1. Fully Reusable OTV (GB and SB) Groundrules and Assumptions

SMALL AND 2-STAGE SMALL DTV (UNMANNED)

- 2-STAGE OTV DDT&E COSTS REPRESENT THE DEVELOPMENT OF THE RECOVERY SYSTEM ONLY. OTHER SUBSYTEMS ARE ASSUMED TO BE THE SAME AS THOSE IN THE SMALL OTV.
- THE NEW 2-STAGE RECOVERY SYSTEM WILL BE MOUNTED TO A SMALL OTV FROM INVENTORY DURING
- 25% COMMONALITY IN RECOVERY SYSTEM (COMMON STRUCTURAL COMPONENTS).

MAN-RATED OTV (12/10K FAYLOAD) 🗅

20% COMMONALITY IN STRUCTURE (COMMON COMPONENTS).

95% COMMONALITY IN RCS (ADDED THRUSTERS).

* 90% COMMÓNALITY IN PROPULSION SYSTEM (ADDED REDUNDANCY).

COMMONALITY IN AVIONICS (ADDED SYSTEM REDUNDANCY AND INTERNALLY REDUNDANT DMU'S).

95% COMMONALITY IN ELECTRICAL POWER (ADDED REDUNDANCY).

20% COMMONALITY IN RECOVERY SYSTEM (COMMON STRUCTURAL COMPONENTS).

(1) COMMONALITY RELATIVE TO SMALL OTV

Table 10.2-2 GB FRS Cost Summary (\$M)

DDT&E (Non-Recurring)		2619
OTV	1656	
Mission Control	867	
Ground Operations	96	
Production		573
Small OTV	495	
Large OTV	78	
Operations (Recurring)		26068
Launch (CLV)	20023	
Mission Control	1743	
OTV Processing	640	
Expend/Amortiz Hardware	418	
Down Cargo Impact	4242	
Total LCC		30260
Discounted		8038

10.2.2.2 OTV Cost

The DDT&E for the three types of stages required for the GB FRS concept is presented in table 10.2-3. The initial stage designated as "small OTV" was sized for a 14.6K lb GEO payload and had a total DDT&E cost of \$1108 million with the largest contributor being a new advanced cryo engine. The advanced engine for GB OTV was estimated to be \$50 million cheaper than for a SB OTV because fewer diagnostic provisions are necessary and no special provisions are required for easy removal and replace on-orbit. GEO payloads up to 22K lbm and occurring early in the mission model were satisfied by using the small OTV flown in a 2 stage mode. The delta DDT&E cost for this step was \$74 million with the key contributor being a larger ballute that was necessary to allow payloads to be returned to GEO.

The third vehicle type was necessary for the manned GEO sortie mission. A larger propellant capacity and ballute was required and man-rating of subsystems was necessary. The resulting delta DDT&E was \$475 million. The DDT&E for all three vehicle types was \$1656 million.

Table 10.2-3. GB FRS OTV DDT&E Cost

!	D180-21	1908-9	
TV ED DDT&E/MFG	25.27 18.66 24.44 8.00 6.43 26.48 39.07 3.55 18.64 16.12 21.58	208.22 15.90 30.00 25.11 41.37 17.05 6.88 2.90 7.14	00·#/#
LARGE OTV MAN-RATED DDT&E/DES DD	19.93 8.86 7.43 0.29 21.14 4.67 14.70 43.05	120.05	
GE OTV OPT/MB DDT&E/MFG	15.83 2.61 1.97	20.41 4.05 0.00 3.92 3.72 1.58 0.61 0.70 1.62	ND *07
2-STAGE COST OP DDT&E/DES	36.93	36.93	
DTV IMIZED DDT&E/MFG	21.94 23.52 23.52 8.00 6.07 25.84 55.98 3.92 17.95 25.33 24.10	238.02 31.99 109.00 81.68 24.70 18.86 7.96 15.22	1107.86
SMALL OTV COST OPTIMI DDT&E/DES DD		572.64	
	VEHTCLE STRUCTURE TANKS TANKS PROFULSTON (LESS ENG) MAIN ENGINES RCS AVIONICS ELECTRICAL POWER THERMAL CONTROL AEROASSIST ASE GSE ASSY & C/O	HARDWARE SUBTOTAL SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT FOOLING & STE SFARES LIAISON ENGR DATA LOGISTICS ENGINEERING SUPPORT SUBTOTAL	VEHICLE TOTAL = \$1656M



The production cost for the GB FRS OTV is \$573 million. The theoretical first unit (TFU) cost for the three vehicle types is presented in table 10.2-4. The number of production units required to satisfy the model is as follows:

• Small vehicle 10 (includes 1 in DDT&E)

Large man-rated vehicle 2 (includes 1 in DDT&E)

The direct OTV operations cost is defined as including launch, expendable and amortized hardware, and recovery. Launch cost varies with the combined weight of the OTV, ASE, and payload. A user's charge approach was used which meant once three-quarters of the launch capacity (full load point) was reached the full launch cost was used (\$70 million for CLV). Cost below the full load point was prorated and no additional cost occurred for launch needs beyond that point. The full load point is 113K lbm for 150 nm/28.5 deg, 102K lbm at 150 nm/63 deg and 90K lbm at 150 nm/90 deg. The launch cost for the missions using a GB FRS are shown in table 10.2-5. The total launch cost was \$20,023 million.

OTV expendable hardware consisted of the ballute at \$0.78 million per flight. Amortized hardware included the heat shield and main engines at \$0.2 M per flight. The total cost in this area was \$418 million.

The down cargo cost named with the type of return vehicle was described in section 8.0. The average cost per year was as follows:

• 1995 - 2001 +\$678M/year (STS)

• 2002 - 2010 -\$ 56M/year (STS II)

10.2.2.3 Ground System Cost

The ground system and operations associated with processing the GB FRS and its payload was described in section 6.0. The DDT&E was estimated to be \$96 million for a processing cell, integration with payload cell, and recovery and support facilities. The processing cost per flight is estimated at \$1.5 million.

10.2.2.4 Mission Control System Cost

The mission control system (MCS) cost covers the necessary facilities, equipment, and planning necessary for a flight. This area was discussed in section 7.0. The

		D180-21908-9	
LARGE OTV MAN RATED TFU	8.17 4.78 5.60 4.00 2.89 13.10 15.50 1.76 6.28 □	7.83 69.91 6.21 0.11 2.17 8.48	78.39
2-STAGE OTV COST OPT/MED BRAKE TFU	5.73	0.71 6.44 0.57 0.01 0.20	7.22
SMALL OTV COST OPTIMIZED TFU	6.40 5.54 4.70 4.00 2.45 10.74 14.46 1.69	6.96 61.93 0.10 1.93	1.90
	VEHICLE STRUCTURE TANKS TANKS FROPULSION (LESS ENG) MAIN ENGINES RCS AVIONICS ELECTRICAL FOWER THERMAL CONTROL ASE	GSE ASSY & C/O HARDWARE SUBTOTAL SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT TOOLING & STE SPARES LIAISON ENGR DATA LOGISTICS ENGINEERING SUPPORT SUBTOTAL	(1) EXPENDABLE HARDWARE

OTV Mission Model, Rev. 9, Scenario 2

Table 10.2-5 Launch Cost for GB FRS Concept

Mission	Payload (Klbs) Up/Down	® Start Weight (KLB)	③ Stage Type	© Lift-Off Weight (KLB)	Cost Per Flight (\$M)	Total Flights
GEO Platform	14.6	80.5	s	82.5	51.1	-
Planetary (C3 = 60)	7.5	59.4	5	61.7	38.0	14
Mult. Pld. Del	12/2	76.8	s	7.8.7	48.7	98
Ind. GEO Sat.	7.0	9.09	S	62.5	38.7	-
Ind. GEO Sat.	10.0	68.4	S	70.4	43.6	7
Ind. GEO Sat.	13.2	76.8	s	7.8.7	48.7	4
Ind. GEO Sat.	13.7	78.2	S	1.08	49.6	
Ind. GEO Sat.	14.6	90.6	\$	82.5	51.1	2
Ind. GEO Sat.	21.8	112.6	25	114.9	70.0	•
Sat. Retrieval	0/10	63.1	SM	65.0	40.3	7
Manned GEO Sort.	12/10	105.1	1	107.3	6.99	16
GEO Shack Unman.	16.7	98.4	2.5	100.8	62.6	-
GEO Shack Manned	25.0	120.7	25	123.0	70.0	-
GEO Shack Log. A	12/10	105.7	2SM	108.2	6.99	4
GEO Shack Log. B	12/10	104.0	7	106.2	65.7	34
Unman. Lunar Orb.	5.0	45.9	8	47.9	29.7	
Unman. Lun. Surf. Expl.	33.0	120.8	. 1	123.0	70.0	-
①Unman. Lun. Surf. D1	73.0	150.0	1	152.2	70.0	4
①Unman. Lun. Surf. D2		95.0	7	97.2	60.2	4
DOD GEO Delivery	10.0	68.4	8	70.3	43.5	86
DOD Med. Inclination	10.0	60.1	S	62.1	42.5	131
DOD High Inclination	4.0	29.2	S	31.2	24.3	16

 The 7310 lunar mission was divided into 2 launches and thus the total flights are greater than that indicated by the basic

mission model Payload + OTV

•

o 2 launches and thus ③ S = Small
dicated by the basic SM = Small with Medium ballute
25 = 2 stage small

1 = Large

Payload + OTV + ASE

resulting cost reflects two levels of technology with the motivation being to reduce the cost per flight contribution. The total MCS DDT&E cost is \$867 million. The total MCS recurring cost is \$1743 million and based on the following:

- 1995 1999 = \$6.1 M per flight
- 2000 2010 = \$3.1 M per flight

10.2.3 SB FRS OTV Concept Cost

10.2.3.1 Cost Summary

The total cost for the SB FRS concept is presented in table 10.2-6. Further discussion of the cost associated with each system element follows:

Table 10.2-6 SB FRS Cost Summary (\$M)

DDT&E (Non-Recurring)		3262
OTV	1562	
Mission Control	867	
Ground Operations	38	
Orbital Support	795	
Production		735
Small OTV	350	
Large OTV	69	
Orbital Support	316	
Operations (Recurring)		25206
Launch	15991	
Mission Control	1603	
OTV Processing	4060	
Expend/Amortiz Hardware	1389	
Orbital Support	1085	
Down Cargo Impact	1077	
Total LCC		29204
Discounted		7812

10.2.3.2 OTV COST

The DDT&E cost for the three types of stages required for the SB FRS concept is shown in table 10.2-7. Application of each stage and their differences is the same as defined for the GB FRS concept. The total DDT&E is \$1562 million.

The production cost for the OTV's is \$419 million. The TFU cost for each staged is presented in table 10.2-8. A total of eight small and two large stages are required, which includes one each as part of the DDT&E cost.

The direct OTV operations cost includes that associated with launch, processing, expendable/amortized hardware, and down cargo impact. The launch cost for the missions using the SB FRS are shown in table 10.2-9.

In addition, there is the launch of propellant delivery tankers, empty SB OTV's, and OTV support accommodations for the Station. The full load factor point is 104K lbm as all launches go to the Station at 250nm/28.5 deg. The total launch cost was \$15,591 million. The OTV orbital processing operations were described in section 5 and 6. The average cost per flight for processing the SB FRS was estimated at \$10.1M. This was based on 52 hours of EVA at \$81.7K/hour and 313 hours of IVA at \$18.7K/hour. The expendable and amortized hardware cost of \$1389 million is based on \$1.0M per flight covering the ballute, heat shield and main engine. In addition, 21 Centurer-G prime stages at an average cost of \$30M is included to cover missions in 1995. The Centaurs are used because the SB FRS by study groundrules was not available until 1996.

The down cargo cost relates to the return of the propellant delivery tanker. The average cost per year varies with the vehicle being used to perform the return flight as shown below.

- 1996 2001 +\$430M/year (STS)
- 2002 2010 -\$167M/year (STS II)

10.2.3.3 Ground System Cost

The ground system cost relates to the recurring processing of the propellant delivery tankers. DDT&E for the necessary facility/equipments is estimated at \$38M. Operations cost associated with OTV processing on-orbit was discussed earlier.

Table 10.2-7. SB FRS OTV DDT&E Cost

		OTV TIMIZED DDT&E/MFG	2-STAGE OTV COST OPT/MED BALLUTE DDT&E/DES DDT&E/MFG	OTV D BALLUTE DDT&E/MFG	LARGE OTV MAN-RATED DDT&E/DES DDT	0TV 9TED DDT&E/MFG
VEHICLE STRUCTURE TANKS PROPULSION (LESS ENG) MAIN ENGINES RCS AVIONICS ELECTRICAL FOWER THERMAL CONTROL AEROASSIST SIACE MAINTENANCE PROV ASE GSE	18.00 8.91 57.44 350.00 1.66 29.50 50.52 14.98 63.17 NC	11.93 14.21 21.42 8.00 11.07 20.83 44.35 17.16 17.16 19.24	43.92	15.82 3.00 2.00	4.19 9.23 2.24 0.33 2.25 15.66 48.11 0.17	10.28 17.55 18.97 8.00 13.56 28.75 37.46 2.50 18.61 0.50 NC 12.44 19.51
HARDWARE SUBTOTAL. SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT TOOLING & STE SPARES LIAISON ENGR DATA LOGISTICS ENGINEERING SUFFORT SUBTOTAL	596.04	31.24 109.00 81.12 14.06 15.22 6.12 7.66 14.84	43.93	20.81 4.58 0.00 4.70 3.71 1.58 0.61 0.80 1.86 17.84	102.48	11.86 30.00 17.25 32.66 15.62 6.10 2.40 5.20 121.10

NOT COSTED

Table 10.2-8. SB FRS OTV TFU Cost

	SMALL OTV COST OPTIMIZED TFU	2-STAGE OTV COST OFT/MED BALLUTE TFU	LARGE OTV MAN RATED TFU
VEHICLE STRUCTURE TANKS PROPULSION (LESS ENG) MAIN ENGINES RCS AVIONICS ELECTRICAL POWER	8.49 8.49 4.00 4.24 11.10		3.70 4.11 4.47 4.00 5.68 13.41
THERMAL CONTROL AEROASSIST SPACE MAINTENANCE PROV ASE GSE ASSY & C/O	1.24 4.83 (7 0.26 NC (7 NC (7 5.72	5.38 TV NC NC 0.67	
HARDWAKE SUBTOTAL	51.66	6.05	65.02
SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT TOOLING & STE SPAKES LIAISON ENGR	4.59	0.54	. 5.78
DATA LOGISTICS ENGINEERING	0.08	0.01	0.10
SUPPORT SUBTOTAL	9	0.73	7.87
VEHICLE TOTAL	57.92	62.9	72.89
(1) EXPENDABLE HARDWARE (2) NOT COSTED	2.00	2.40	2.50

OTV Mission Model, Rev. 9, Scenario 2

Table 10.2-9 Launch Cost for SB FRS Concept

					The state of the s	
Mission	Payload (Klbs) Up/Down	O Start Weight (KLB)	© Stage Type	① Lift-Off Weight (KLB)	Cost Per Flight (\$M)	Total Flights
GEO Platform	14.6	8.69	S	14.6	8.6	ı
Planetary (C3 = 60)	7.5	51.2	S	7.5	5.0	14
Mult. Pld. Del	12/2	66.3	S	12.0	8.1	98
Ind. GEO Sat.	7.0	50.3	S	7.0	4.7	-
Ind. GEO Sat.	10.0	58.0	S	10.0	6.7	2
Ind. GEO Sat.	13.2	6.3	S	13.2	8.9	4
Ind. GEO Sat.	13.7	67.6	. s	13.7	9.2	-
Ind. GEO Sat.	14.6	8.69	S	14.6	9.8	2
Ind. GEO Sat.	21.8	98.8	2.5	21.8	14.7	•
Sat. Retrieval	0/10	52.8	SM	l	1	2
Manned GEO Sort.	12/10	94.2		12.0	8.1	16
GEO Shack Unman.	16.7	84.9	25	16.7	11.2	-
GEO Shack Manned	25.0	106.6	25	25.0	16.8	-
GEO Shack Log. A	12/10	92.5	2SM	12.0	8.1	4
GEO Shack Log. B	12/10	94.0	7	12.0	8.1	34
Unman. Lunar Orb.	5.0	39.0	S	5.0	3.4	8
Unman. Lun. Surf. Expl.	33.0	114.2	1	33.0	22.2	-
Unman. Lun. Surf. Del.	73.0	234.6	77	73.0	49.1	4
DOD GEO Delivery	10.0	58.0	S	10.0	6.7	86
DOD Med. Inclination	10.0	61.1	S	10.0	6.7	131
DOD High Inclination	4.0	75.8	7	4.0	2.7	16
Tankers-Lo. Platform	150.0			150.0	70.0	171
Empty OTV's	88.0			88.0	59.2	2
Platform Hardware	113.0			113.0	70.0	1.5

<u></u>

① Payload + OTV③ Payload + OTV + ASE

SmallSmall with Medium balluteLarge2 Stage Large S = 17 S = 21

10.2.3.4 Mission Control System Cost.

The mission control cost contributors are the same as defined for the GB FRS concept. The operations cost is less because the first year (1995) missions are done with Centaur-G prime and it was assumed operations cost are included in its cost per flight.

10.2.3.5 Orbital Support Cost

Orbital support covers the accommodations at the Space Station (see section 5) and the propellant delivery tanker. The \$795M DDT&E cost includes \$470M for accommodations (hangar, servicing equipment, and propellant storage system) and \$325M for the tanker. The production cost reflects a second hangar and propellant storage tank set (\$150M total) as well as two additional storage tank sets (\$50M each) in the way of accommodations and two additional propellant delivery tankers (\$33M each). Orbital support operations cost reflects an average of \$2.7 million per SB FRS flight and is comprised of the contributions shown in table 10.2-10.

Table 10.2-10 Orbital Support Contributions

	Element	Cost/Flight
•	Hangar Use ①	\$0.25M
. •	Manipulator Use ①	\$0.07M
•	Tanker Processing	\$0.35M
•	OMV Support (Tanker and payload retrieval from CLV)	\$0.42M
•	Launch OTV Expend Hardware	\$1.25M
•	Airlock Use ①	\$0.36M
		\$2.70M

① per study groundrules

10.3 PARTIALLY REUSABLE OTV'S

The costs associated with the GB and SB partially reusable system (PRS) concepts are presented. Both concepts use two basic stage types and three different aerobrake modules as shown in figure 10.3-1 to satisfy the mission model. The GB and SB PRS concepts were described in section 3.4 and 3.8, respectively.

10.3.1 Unique Groundrules and Assumptions

In addition to the common groundrules for all concepts, unique groundrules apply to the PRS concepts as shown in table 10.3-1 and 10.3-2. The majority of the items deal with commonality between the stages and between the aerobrake modules for return of propulsion/avionics, payloads, and crew module.

10.3.2 GB PRS OTV Concept Cost

10.3.2.1 Cost Summary

The total cost for the GB PRS concept, in performing the Rev. 9 Scenario 2 mission model, is presented in table 10.3-3. Further discussion of each system element follows.

Table 10.3-3 GB PRS Cost Summary (\$M)

DDT&E (Non-Recur)		2,864
OTV	1,814	
Mission Control	964	
Ground System	96	
Production		432
P/A Module	404	
P/L Module	28	
Operations (Recurring)		27,773
Launch (CLV)	19,902	
Mission Control	2,188	
OTV Processing	683	
Expend/Amortize Hdw	3,570	
Down Cargo	1,429	
Total LCC		31,068
Discounted		8,029

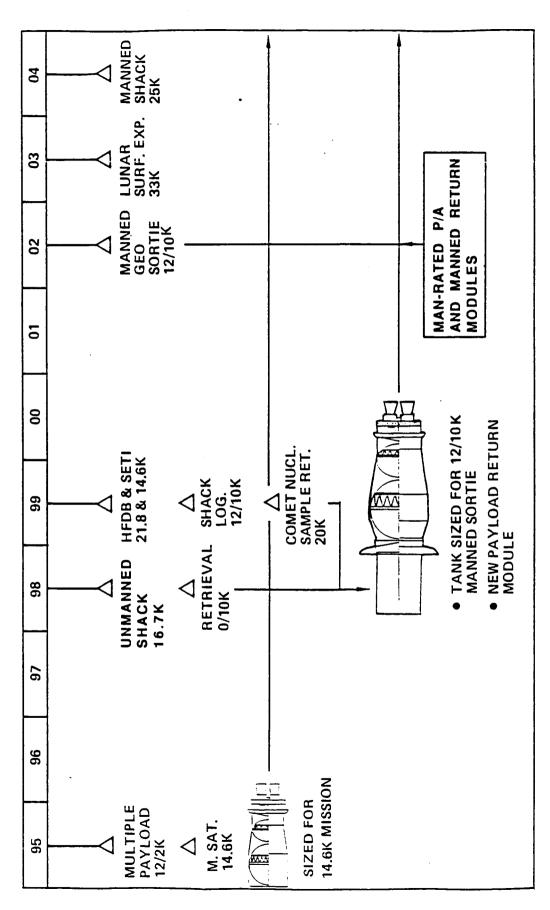


Figure 10.3-1. PRS OTV Mission Application

Table 10.3-1. Partially Reusable OTV (GB and SB) Groundrules and Assumptions

SMALL AND LARGE STAGE (UNMANNED)

* 10% COMMONALITY IN TANK SET (SIMILAR TYPE OF STRUCTURE).

* PA MODULE WILL BE THE SAME IN BOTH CONFIGURATIONS

AEROASSIST MODULE FOR RETURN PAYLOAD ()>

* 50% COMMONALITY IN STRUCTURE

* 75% COMMONALITY IN RCS

* 100% COMMONALITY IN AVIONICS

* BOX COMMONALITY IN ELECRICAL POWER

* 10% COMMONALITY IN RECOVERY SYSTEM

☼ COMMONALITY RELATIVE TO PA MODULE

Table 10.3-2. Partially Reusable OTV (GB and SB) Groundrules and Assumptions

MAN-RATED OTV

- * NO CHANGE IN LARGE TANK SET DESIGN.
- * 100% COMMONALITY IN PA MODULE STRUCTURE.
- * 100% COMMONALITY IN PA MODULE THERMAL PROTECTION.
- 5% COMMONALITY IN PA MODULE RCS (ADDED THRUSTERS).
- * 90% COMMONALITY IN PA MODULE PROPULSION SYSTEM (ADDED REDUNDANCY).
- 50% COMMONALITY IN PA MODULE AVIONICS (ADDED SYSTEM REDUNDANCY AND INTERNALLY REDUNDANT DMU'S) *
- 95% COMMONALITY IN PA MODULE ELECTRICAL FOWER (ADDED REDUNDANCY).
- * 100% COMMONALITY IN PA MODULE RECOVERY SYSTEM.

AEROASSIST FOR CREW MODULE

- 75% COMMONALITY IN STRUCTURE (SIMILAR TO PAYLOAD RETURN MODULE).
- * 75% COMMONALITY IN RCS (ADDED THRUSTERS; MODIFIED PRESSURE SYSTEM).
- * 100% COMMONALITY IN AVIONICS (SAME AS PA MODULE).
- * 100% COMMONALITY IN ELECTRICAL POWER (SAME AS PA MODULE).
- * 15% COMMONALITY IN RECOVERY SYSTEM (COMMON STRUCTURAL COMPONENTS)

10.3.2.2 OTV Cost

The DDT&E for the GB PRS OTV including stages and aerobrake modules is \$1814 million with the breakdown presented in table 10.3-4. the small stage and aerobrake module for propulsion/avionics has a cost contribution of \$1092 million. To satisfy more demanding missions, a larger tank set is required in addition to another aerobrake module to return unmanned payloads. The resulting DDT&E cost is \$363 million. The same type of OTV (tank set plus P/A module) is used for manned missions, however, all systems are man-rated. In addition, another type of brake is required for the crew module involving a DDT&E cost of \$358 million.

The production cost for this OTV concept of \$432 million only reflects the aerobrake modules because they are the only reusable hardware. Tank sets and the brakes themselves are expendable hardware under the operations cost. The TFU costs for all elements of the GB PRS configurations is presented in table 10.3-5. The number of production units for each aerobrake module is as follows:

•	P/A Module	11 (includes 1 in DDTE)
•	P/L Module	2 (includes 1 in DDTE)
•	Crew Cabin Module	1 (includes 1 in DDTE)

Operations cost directly associated with the OTV include launch, expendable/amortized hardware, and down cargo. The total launch cost of \$19,902 million is comprised of the individual mission costs presented in table 10.3-6. The full load point for user charge calculation is the same as described for the GB PRS concept. The expendable/amortized hardware cost of \$3570 million covers the aerobrakes (not entire module) and tank sets. The TFU and number of units involved is shown in table 10.3-7.

Table 10.3-7 GB PRS Expendable Hardware

<u>Element</u>	TFU (\$M)	<u>Units</u>
P/A Module Brake	6.7	422
Crew Module Brake	8.4	16
Payload Module Brake	11.9	40
Small Tankset	17.8	361
Large Tankset	22.3	56

COMBINED TOTAL - \$1814

LARGE OTV N-RATED/CREW MODULE RET DT&E/DES DOT&E/MFG	0.31 5.77 2.38 18.30 8.00	20.91 0.05 0.11	.56 123.6	·	0.00 0.00	0.18 3.04 0.28 0.79	.42 29.8	6.61 53.8	8.77 22.08	3.4	8.19 30.00 10.03	7000	 	00.201	358,46
TV HODULE MA DT&E/MFG D	-		0.00	22.73 19.45 18.79 1.39 2.39	14.	1.31 7.18 0.64	35.7	9.7	12,68 16,29	264.4	3.8		5.7	98.86	363.36
LARGE O LG TANK / PL DDT&E/DES D	-		0.00	28 30.52 00.326 00.326 64.72	. 9	0.20 3.20 1.20 1.28	0-1	0.4						•	ŧ
7V 11 2E D 10 7 LE / MFG	14.3 21.4 8.0		149.3	. 21-20 20-40 20-20 20-20 20-20 20-20	58.9		1	0.00		7.667	30.33 109.00 76.83		14.3	292.47	1092.22
SMALL OT COST OPTIM DDT&E/DES D	15.35 56.16 300.00	31.31 4.69 8.34	2.7	22 138 138 138 138 138 148 148 148 148 148 148 148 148 148 14	9.8		1	00.00	1	•				ı	1
	PA MODULE STRUCTURE PROPULSION (LESS ENG) HAIN ENGINES	AVIONICS ELECTRICAL POWER THERMAL CONTROL EXPENDABLE BRAKE	PA MODULE SUBTOTAL	TANK MODULE STRUCTURE TANKS PROPULSION AVIONICS THERMAL CONTROL ELECTRICAL POWER	TANK SUBTOTAL	BRAKE MODULE STRUCTURE RCS AVIONICS FLETATOR	ST	BRAKE SUBTOTAL	ASE GSE ASSY & C/D	HARDWARE SUBTOTAL	SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT	SPARES LIAISON ENGR	LOGISTICS ENGINEERING	SUPPORT SUBTOTAL	VEHICLE TOTAL

DOULE SHCTHRE SHCTHRE	COST OPTIMIZED TFU 4.39	LARGE OTV LG TANK/PL HOD TFU	MAN-RATED/CREW MODULE RET TFU 4.38
HATO TO THE STATE OF THE STATE	24.001.03 20.001.03 20.001.03 20.001.03 20.001.03	5.26	18.86 19.86 10.86
SUBTOTAL	45.84		54.44
TANK HODULE STRUCTURE TANKS PROPULSION AVIONICS: THERMAL CONTROL ELECTRICAL POWER	00000000000000000000000000000000000000	7.59 4.59 0.64 0.64 0.17	4.5.4.4.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
RAKE NODULE STRUCTURE RCS AUTONICS ELECTRICAL POWER AERDASSIST			0.45 3.21 11.61 6.69
SUBTOTAL	0.00	31.22	32.64
C/O SUBTOTAL	7.62	6.31	10.92
SYSTEM ENGR & INTEG SOFTHARE SYSTEST CONDUCT TOOL ING & STE SPARES LIAISON ENGR	. 00.4	4.87	8.7 0.1
ERING SUBTOTAL	2.11	1.75	3.02
TOTAL	75.79	35.77	94.73
EXPENDABLE HARDWARE	24.60	32.90	29.40

Table 10.3-6 Launch Cost for GB PRS Concept

S S S S S S S S S S S S S S S S S S S	Mission	Payload (Klbs) Up/Down	® Start Weight (KLB)	(d) Stage Type	(KLB)	Cost Per Flight (\$M)	Total Flights
=60) 7.5 56.8 5 58.6 36.3 12/2 12/2 75.7 5 77.5 48.0 12/2 75.7 5 77.5 48.0 8.0 12/2 7.0 58.8 5 60.6 37.5 48.0 11 10.0 66.6 5 68.4 42.4	GEO Platform	14.6	78.6	S	80.5	49.9	-
122 75.7 5 48.0 48.0 120 58.8 5 60.6 37.5 8.7 120 66.6 5 60.6 37.5 8.7 8.7 42.4 8.7 132 14.9 5 66.4 42.4 </td <td>Planetary (C3 = 60)</td> <td>7.5</td> <td>56.8</td> <td>S</td> <td>58.6</td> <td>36.3</td> <td>14</td>	Planetary (C3 = 60)	7.5	56.8	S	58.6	36.3	14
7.0 58.8 5 60.6 37.5 110.0 66.6 5 68.4 42.4 113.2 74.9 5 76.8 47.6 11.2 76.3 5 78.1 48.4 78.6 11.2 76.3 5 78.1 48.4 76.2 78.6 11.2 71.8 76.3 5 78.7 48.4 76.2	Mult. Pld. Del	12/2	75.7	S	77.5	48.0	98
100 66.6 5 68.4 42.4 13.2 74.9 5 76.8 47.6 13.7 76.3 5 78.1 48.4 14.6 78.6 5 80.5 50.2 14.6 78.6 5 80.5 50.2 14.6 78.6 5 62.4 48.4 10.1 10.9 10.0 60.5 5 62.4 38.7 Sortie 12/10 121.0 LM 123.8 70.0 70.0 nman. 16.7 95.9 LU 119.9 70.0 70.0 sortie 25.0 117.9 LU 97.9 60.6 70.0 sort. Expl. 33.0 122.4 LU 124.5 70.0 70.0 surf. Expl. 73.0 LU 124.5 70.0 70.0 70.0 surf. Dt 73.0 LU 124.5 70.0 70.0 70.0 70.0 70.0 70.0	Ind. GEO Sat.	7.0	58.8	S	9:09	37.5	•
13.2 74.9 5 76.8 47.6 13.7 76.3 5 78.1 48.4 14.6 78.6 5 80.5 50.2 14.6 78.6 5 80.5 50.2 12.1 109.9 LU 111.9 69.4 69.4 Sortie 12.10 121.0 LM 123.8 70.0 anned 25.0 117.9 LU 19.9 70.0 anned 25.0 117.9 LU 19.9 70.0 ag. 12/10 119.9 LU 121.9 70.0 surf. Expl. 33.0 122.4 LU 124.5 70.0 surf. D1 73.0 97.0 LU 99.1 61.3 in. Surf. D2 - 148.0 LU 150.1 70.0 in. surf. D2 - 148.0 5 68.4 42.4 dination 4.0 5 60.9 41.0 71.1	Ind. GEO Sat.	10.0	9.99	S	68.4	42.4	2
13.7 76.3 5 78.1 48.4 48.4 14.6 78.6 5 80.5 50.2 14.6 78.6 5 80.5 50.2 10.1 11.8 109.9 LU 111.9 69.4 Sortie 12/10 121.0 LM 123.8 70.0 anned 25.0 117.9 LU 97.9 60.6 70.0 ag. 12/10 117.9 LU 121.9 70.0 70.0 ag. 12/10 119.9 LU 121.9 70.0 70.0 Surf. Expl. 33.0 44.7 \$ 46.6 29.1 70.0 Surf. Expl. 73.0 97.0 LU 99.1 61.3 70.0 Iniv. Surf. D2 - 1 148.0 LU 124.5 70.0 Inivery 10.0 59.1 5 68.4 42.4 70.0 Inination 4.0 5 60.9 41.0	Ind. GEO Sat.	13.2	74.9	S	76.8	47.6	4
14.6 78.6 5 80.5 50.2 1.1 21.8 109.9 LU 111.9 69.4 5 Sortie 12/10 60.5 5 62.4 38.7 70.0 nman. 16.7 95.9 LU 97.9 60.6 70.0 anned 25.0 117.9 LU 119.9 70.0 70.0 og. 12/10 119.9 LU 121.9 70.0 70.0 r. Orb. 5.0 44.7 \$ 46.6 29.1 70.0 Surf. Expl. 33.0 122.4 LU 124.5 70.0 70.0 Surf. D1 73.0 97.0 LU 99.1 61.3 70.0 in. Surf. D1 73.0 66.6 5 68.4 42.4 70.0 dination 10.0 59.1 5 60.9 41.0 70.0 dination 4.0 5 66.9 41.0 71.1 71.1 <td>Ind. GEO Sat.</td> <td>13.7</td> <td>76.3</td> <td>S</td> <td>78.1</td> <td>48.4</td> <td>-</td>	Ind. GEO Sat.	13.7	76.3	S	78.1	48.4	-
21.8 109.9 LU 111.9 69.4 89.7 69.4 38.7 70.0 12/10 121.0 LM 123.8 70.0 7	Ind. GEO Sat.	14.6	78.6	S	80.5	50.2	7
no/10 60.5 S 62.4 38.7 12/10 121.0 LM 123.8 70.0 16.7 95.9 LU 97.9 60.6 25.0 117.9 LU 119.9 70.0 xpl 35.0 44.7 S 46.6 29.1 xpl 33.0 122.4 LU 124.5 70.0 1 73.0 97.0 LU 99.1 61.3 70.0 .D2 - 148.0 LU 150.1 70.0 70.0 n 10.0 66.6 S 68.4 42.4 70.0 n 10.0 59.1 S 60.9 41.0 70.0 n 40.0 59.1 S 60.9 41.0 70.0 n 40.0 59.1 S 60.9 41.0 70.0	Ind. GEO Sat.	21.8	109.9	רח	111.9	69.4	1
12/10 121.0 LM 123.8 70.0 16.7 95.9 LU 97.9 60.6 25.0 117.9 LU 119.9 70.0 xpl. 12/10 119.9 70.0 70.0 xpl. 33.0 44.7 \$ - 46.6 29.1 70.0 1 73.0 97.0 LU 99.1 61.3 70.0 1 10.0 66.6 \$ 68.4 42.4 70.0 n 10.0 59.1 \$ 68.4 42.4 70.0 n 4.0 59.1 \$ 66.9 41.0 70.0 70.0	Sat. Retrieval	0/10	60.5	S	62.4	38.7	2
16.7 95.9 LU 97.9 60.6 25.0 117.9 LU 119.9 70.0 12/10 119.9 LU 121.9 70.0 12.4 44.7 \$ 46.6 29.1 70.0 12.4 LU 124.5 70.0	Manned GEO Sortie	12/10	121.0	ΙM	123.8	0.07	16
25.0 117.9 LU 119.9 70.0 12/10 119.9 LU 121.9 70.0 12.10 44.7 S 46.6 29.1 70.0 11.2.4 LU 124.5 70.0 <td>GEO Shack Unman.</td> <td>16.7</td> <td>95.9</td> <td>ΓΩ</td> <td>97.9</td> <td>9.09</td> <td>1</td>	GEO Shack Unman.	16.7	95.9	ΓΩ	97.9	9.09	1
12/10 119.9 LU 121.9 70.0 M. 33.0 44.7 S 46.6 29.1 M. 33.0 122.4 LU 124.5 70.0 D2 - 148.0 LU 99.1 61.3 70.0 D2 - 148.0 LU 150.1 70.0 70.0 D3 - 66.6 S 68.4 42.4 70.0 D4 10.0 59.1 S 60.9 41.0 71.1 D4 4.0 S 30.7 21.1 71.1	GEO Shack Manned	25.0	117.9	נח	119.9	70.0	ļ
5.0 44.7 5 46.6 29.1 70.0 33.0 122.4 LU 124.5 70.0 70.0 12.1 97.0 LU 99.1 61.3 70.0 12.1 10.0 148.0 LU 150.1 70.0 70.0 10.0 66.6 5 68.4 42.4 70.0 70.0 10.0 59.1 5 60.9 41.0 70.0 70.0 4.0 28.8 5 30.7 21.1 70.0 70.0	GEO Shack Log.	12/10	119.9	רח	121.9	70.0	38
M. 33.0 122.4 LU 124.5 70.0 73.0 97.0 LU 99.1 61.3 61.3 22 - 148.0 LU 150.1 70.0 70.0 10.0 66.6 5 68.4 42.4 70.0 70.0 10.0 59.1 5 60.9 41.0 70.1 70.1 70.1 4.0 28.8 5 30.7 21.1 70.1	Unman. Lunar Orb.	5.0	44.7	S	46.6	1.62	8
73.0 97.0 LU 99.1 61.3 52 - 148.0 LU 150.1 70.0 10.0 66.6 S 68.4 42.4 41.0 10.0 59.1 S 60.9 41.0 41.0 4.0 28.8 S 30.7 21.1 21.1	Unman. Lun. Surf. Expl.	33.0	122.4	רח	124.5	0.07	l l
52 — 148.0 LU 150.1 70.0 10.0 66.6 \$ 68.4 42.4 10.0 59.1 \$ 60.9 41.0 4.0 28.8 \$ 30.7 21.1	Unman. Lun. Surf. D1	73.0	97.0	Π	99.1	6.1.3	4
10.0 66.6 S 68.4 42.4 10.0 59.1 S 60.9 41.0 4.0 28.8 S 30.7 21.1	①Unman. Lun. Surf. D2	ı	148.0	ΠΊ	150.1	0.07	Þ
10.0 59.1 \$ 60.9 41.0 4.0 28.8 \$ 30.7 21.1	DOD GEO Delivery	10.0	9.99	S	68.4	42.4	86
4.0 28.8 5 30.7 21.1	DOD Med. Inclination	10.0	59.1	S	6.09	41.0	131
	DOD High Inclination	4.0	28.8	\$	30.7	21.1	16

① The 7310 lunar mission was divided into 2 launches

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LU = Large Unmanned LM = Large Manned \oplus S = Small

The down cargo cost of \$1429 million reflects only the return of the aerobrake modules because the tanksets and brakes are expended at the end of each flight. The return analysis was described in section 8.2. The average annual return cost is as follows:

1995 - 2001 (STS) + \$262 million
 2002 - 2010 (STS II) - \$45 million

10.3.2.3 Ground System Cost

The ground system associated with the GB PRS was described in section 6.0. The DDT&E is estimated at \$96 million and vehicle processing cost is based on \$1.6 million per flight.

10.3.2.4 Mission Control Cost

The mission control associated with the GB PRS was discussed in section 7.0. The DDT&E cost of \$964 million reflects an initial system followed by an upgrade in technology to reduce the cost per flight. The associated operations cost of \$2188 million reflects the following:

1995 - 2000 \$6.6 M/flight
 2001 - 2010 \$4.2 M/flight

10.3.3 SB PRS OTV Concept Cost

10.3.3.1 Cost Summary

The cost breakdown for the SB PRS concept in performing the Rev. 9 Scenario 2 mission model is presented in table 10.3-8. Further breakdown of each major system element follows:

Table 10.3-8 SB PRS Cost Summary (\$M)

DDT&E (Non-Recurring)		3,002
OTV	1,800	
Mission Control	954	
Ground System	95	
Orbital Support	153	
Production		322
P/A and P/L Modules	272	
Orbital Support	50	
Operations (Recurring)		31,228
Launch (CLV)	20,379	
Mission Control	2,049	
OTV Processing	3,979	
Expand/Amortize Hrdw	4,414	
Orbital Support	406	
Total LCC		34,552
Discounted		8,510

10.3.3.2 OTV

The DDT&E cost for the stages and aerobrake modules is \$1800 million. The breakdown for the stages and aerobrake modules is presented in table 10.3-9. As in the GB PRS concept, a small OTV with P/A module, a larger OTV with payload return module and a man-rated large stage with crew module return aerobrake module are required.

The production cost of the OTV relates only to the aerobrake modules because the tanksets are expended after each flight. The TFU for all elements of the SB PRS are shown in table 10.3-10. The number of production units is as follows:

•	P/A Module	8 (incl 1 in DDT&E)
•	P/L Return Module	2 (incl 1 in DDT&E)
•	Crew Module Return Module	1 (incl 1 in DDT&E)

The direct operations costs for the OTV element include that associated with launch, expended/amortized hardware and OTV processing. The total launch cost of

LARGE OTV EDCHEW MODULE RET DES DDT&E/NFG	2.44 15.9 B.0	000000000000000000000000000000000000000	8.07 114.7		0.00 0.00	0.18 0.28 1.68 1.42	6.69 54.5	8.4 21.0	243.48	30.00 9.64 9.64 16.92 3.28 3.28	102.69	346.17	
V ETURN MAN-BATE T&E/HFG DDT&E/		2	0.00	23.75 15.98 18.79 2.38 0.67	2.9	1.31 7.94 0.64 14.91 35.70	0.50	12.24	7.7		96.80	354.54	
LARGE DT LG TANK/PL R DDT&E/DES DD			00.0	6.144 0.134 0.134 0.134	4	0 3.56 0.286 0.388 52.488	13	,			•	•	
OTV IMIZED DDT&E/MFG	8.01 8.4.0	45.63 45.63 17.69	7.0	19.19.20.23.140.20.72	8	•	00.00	21.8 23.5	2.6	0 0 0 0 0 0 0 0 0 0 0 0 0 0	286.78	1099.45	
SMALL COST OPT DDT&E/DES	12.56 57.99 350.00	527.183 527.38 3.94 1.94	3.0	25.13.28 13.28 2.28 1.55	12		0.00						
	PA MODULE STRUCTURE PROPULSTON (LESS ENG) MAIN FNGTUFS	NEW T	DULE SUBTO	TANK MODULE STRUCTURE TANKS PROPULSION AVIONICS THERMAL CONTROL ELECTRICAL POWER	TANK SUBTOTAL	BRAKE MODULE STRUCTURE RCS AVIONICS ELECTRICAL POWER REUSABLE AEROASSIST	BRAKE SUBTOTAL	ASE 65E ASSY & C/0	HARDWARE SUBTOTAL	SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT TODLING & STE SPARES LIAISON ENGR LOGISTICS	DRT 9	VEHICLE TOTAL	COMBINIED TOTAL 1800

L	•					01V-19
LARGE OTV MAN-RATED/CREW MODULE RET TFU	12.58 12.58 12.58 1.5.21 0.32 0.32 0.32	7.03 3.80 0.45 0.93 0.93	32.88	10.59	8.47 0.15 2.93 11.55	29.40
LARGE DTV LG TANK/PL MOD TFU	5.52	7.03 3.03 4.180 0.93 0.93 1.6.59	3.05 8.05 10.25 10.25 9.46	59.81	4.81 0.09 1.73 6.63	32.90
SHALL OTV COST OPTIMIZED TFU	34.50 3.50	5.65 3.29 3.29 3.64 0.77 0.14	0.00	59.94	5.34 0.09 1.87 7.31	
	PA MODULE STRUCTURE PROPULSTON (LESS ENG) MATH ENGINES RCS AVIDNICS ELECTRICAL POWER THERNAL CONTROL EXPENDABLE BRAKE SPACE HAINT PROV		BRAKE HODULE STRUCTURE RCS AVIONICS ELECTRICAL POWER AEROASSIST BRAKE SUBTOTAL	ASE BSE ASSY & C/O HARDWARE SUBTOTAL	SYSTEM ENGR & INTEG SOFTWARE SYSTEST CONDUCT TOOLING & STE SPARES LIAISON ENGR DATA LOGISTICS ENGINEERING BUPPORT SUBTOTAL	

\$20,379 million reflects launching payloads, propellant tanksets, aerobrakes, and support accommodations at the Space Station (and the launching of 21 Centaur G prime upper stages with payloads during 1995. The resulting cost per flight for each of the mission types is shown in table 10.3-11. A users charge approach was used with 104 K lbm being the full load point when the launch goes to the Space Station at 250 nm and 28.5 degree. The expended/amortized hardware cost of \$4414 million reflects the tanksets and aerobrakes and also 21 Centaur G primes (\$987 million) used during 1995 since space basing was not possible until 1996. The TFU and number of units for the OTV elements is presented in table 10.3-12.

Table 10.3-12 SB PRS Expendable Hardware

<u>Element</u>	<u>TFU (\$M)</u>	<u>Units</u>
P/A Module Brake	6.7	401
P/L Module Brake	8.4	16
Crew Module Return Module Brake	11.9	49
Small Tankset	17.6	336
Large Tankset	21.0	65

The orbital processing cost for the SB PRS is \$3,979. This is based on \$9.8 million per flight which in turn reflects 52 hours of EVA and 287 hours of IVA and includes a \$1.0 million contribution for the ground processing of the aerobrake/tankset/payload combination.

10.3.3.3 Ground System Cost

The ground system associated with the SB PRS was described in section 6.0. The DDT&E estimate of \$95 million reflects the facilities/equipment necessary to allow processing of an aerobrake/tankset/payload combination for each OTV mission. the ground processing cost per flight of these elements has been included in the OTV processing cost line item.

10.3.3.4 Mission Control Cost

The mission control system for the SB PRS concept was discussed in section 7.0. The DDT&E cost of \$954 million reflects an initial system followed by an upgrade to reduce cost per flight. The operations cost of \$2,049 million reflects the following cost per flight:

Table 10.3-11 Launch Cost for SB PRS Concept

Mission	Payload (Kibs)	Launch Weight (KLB)	Stage Type	Lift-Off Weight (KLB)	Cost Per Flight (\$M)	Total Flights
	14.6	71.7	S	73.5	49.5	1
GEO Platform	7.5	50.7	\$	52.5	35.3	14
Planetary (C3 = 00)	000	69.2	s	71.0	47.8	98
Mult. Pla. Del	7/71	52.2	\$	54.0	36.3	
Ind. GEO Sat.	0.7	0 0 2	\ \	61.7	41.5	7
Ind. GEO Sat.	10.0	33.3		0 00	0.70	4
Ind. GEO Sat.	13.2	68.1	s	69.9	0.74	
Ind. GEO Sat.	13.7	69.4	\$	71.2	47.9	
Ind GEO Sat	14.6	7.17	S	73.5	49.5	2
Ind GEO Sat	21.8	100.5	nı	102.5	0.69	-
Cat Betrieval	0/10	55.4	01	57.4	38.6	2
Manad GEO Sortia	12/10	113.0	ПМ	115.1	70.0	16
Mallited CLO Society	16.7	86.8	3	88.8	59.8	-
GEO SHACK OILLIAM.	25.0	108.3	23	110.3	70.0	1
GEO Shack Manned	12/10	116.6	nı	118.6	70.0	38
GEO Shack Log-		39.7	s	41.5	95.2	3
Unman. Lunar Oro.	0.0	117.4	=	119.4	70.0	-
Unman. Lun. Surf. Expl.	33.0			148.0	70.0	4
①Unman. Lun. Surf. D1	73.0	146.0	CO	200		•
①Unman. Lun. Surf. D2	-	89.0	רח	91.0	61.2	4
DOD GEO Delivery	10.0	59.9	S	61.7	41.5	86
DOD Med. Inclination	10.0	64.2	S	0.99	44.4	131
DOD High Inclination	4.0	86.0	\$	87.8	29.0	16
Platform Hardware		113.0		113.0	70.0	-

© 7310 lunar mission split into 2 launches

•	1996 - 1999	\$6.6	M/flight
•	2000 - 2010	\$4.2	M/flight

10.3.3.5 Orbital Support Cost

Orbital support covers the accommodations necessary at the Space Station to allow preparation of the OTV for each flight. The DDT&E cost of \$153 million relates to the small hangar and vehicle assembly/checkout equipment that is required. The production cost of \$50 million relates to the second set of accommodations equipment (the first set is part of the DDT&E cost). The orbital support operations cost of \$406 million reflects \$1.0 million cost per flight contributed as shown in table 10.3-13.

Table 10.3-13 Orbital Support for SB PRS

Element	Contribution (\$M)
Hanger Use ①	0.25
Manipulator Vac ①	0.07
OMV Support	0.32
Airlock Use ①	0.36
	Total 1.00

① At station

10.4 EXPENDABLE OTV'S

The costs associated with an all-propulsive expendable OTV concept and an expendable with aeroassisted payload return are presented. The stage approach for the two concepts is different and accordingly the mission application and unique groundrules are different.

10.4.1 Expendable All-Propulsive OTV

10.4.1.1 Stage Approach and Groundrules

The stage approach used to satisfy the mission model is shown in figure 10.4-1. A small stage is developed to deliver payloads of 14.6K lbm GEO equivalent. A larger stage is developed to deliver payloads up to 21.8K lbm GEO equivalent. Use of two of these stages in a two stage mode and man-rating the subsystems allows the manned GEO sortic missions to be performed. The unique groundrules associated with the expendable stage are presented in table 10.4-1. Again, the majority of the groundrules relate to commonality between stages.

10.4.1.2 Cost Summary

The total cost for the expendable all propulsive OTV concept is presented in table 10.4-2. Further discussion of each system element follows.

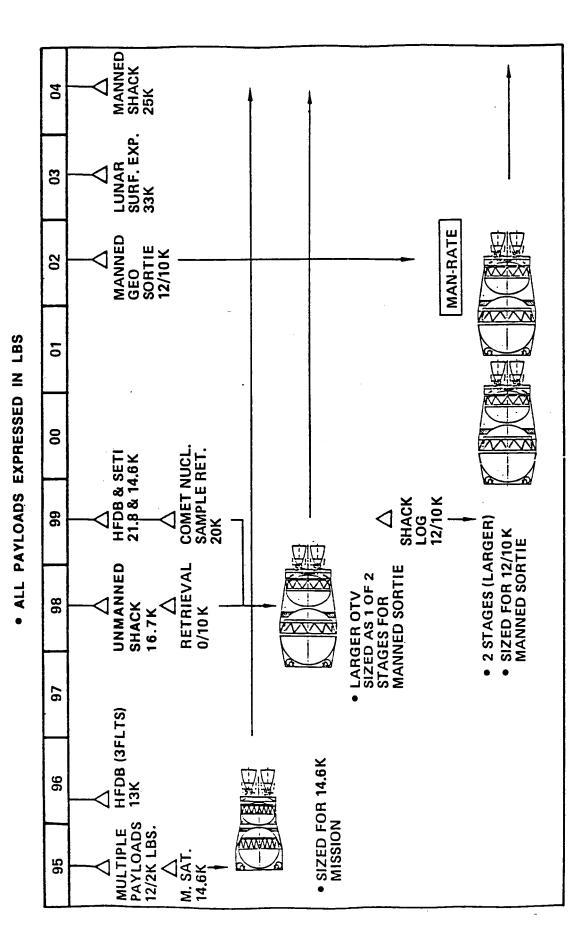


Figure 10.4-1. Expendable OTV Mission Application

Table 10.4-1. Expendable OTV Groundrules and Assumptions

SMALL AND LARGE OTY (UNMANNED)

* BO% COMMONALITY IN RCS (MODIFIED PRESSURE SYSTEM).

* 70% COMMONALITY IN PROPULSION SYSTEM (MODIFIED PLUMBING SYSTEMS).

* 100% COMMONALITY IN AVIONICS.

25% COMMONALITY IN ELECTRICAL POWER (FUEL CELLS WERE USED AS POWER SOURCE IN FLACE OF BATTERIES).

MAN-RATED OTY D

* 100% COMMONALITY IN STRUCTURE.

* 100% COMMONALITY IN THERMAL PROTECTION.

* 95% COMMONALITY IN RCS (ADDED THRUSTERS).

* 90% COMMONALITY IN PROPULSION SYSTEM (ADDED REDUNDANCY).

50% COMMONALITY IN AVIONICS (ADDED SYSTEM REDUNDANCY AND INTERNALLY REDUNDANT DMU'S). *

* 90% COMMONALITY IN ELECTRICAL POWER (ADDED REDUNDANCY).

☼ COMMON RELATIVE TO LARGE UNMANNED OTV

Table 10.4-2 Expendable OTV Cost Summary

DTT&E (Non-Recurring)		2,092
OTV	1,347	
Ground System	120	
Mission Control	623	
Production		0
Operations (Recur)		23,308
Launch (CLV)	13,976	
Mission Control	1,473	
OTV Processing	1,153	
Expendable/Hrdw	6,706	
Down-Cargo	0	
	Total LCC	25,400
	Discounted	6,237

10.4.1.3 OTV Cost

The DDT&E cost for the OTV portion of the expendable concept is estimated at \$1,347 million. Three development steps are involved with the cost breakdown shown in table 10.4-3. The small stage had a cost of \$730 million; the large stage required an additional \$349 million, and man-rating of the large stage required \$268 million.

No production cost occurs with this concept because it involves all expendable hardware and is collected under the operations cost category.

The OTV related operations cost deals with launch and expendable hardware. The launch cost, based on use of CLV and the users charge approach, contributes \$13,976 million. The cost per mission type is shown in table 10.4-4. The TFU cost breakdown for the three expendable stages is presented in table 10.4-5. The number of stages involved is as follows:

•	Small Stage	346
•	Large Stage	109 (includes 46 two stage flights)
•	Large Manned Stage	32 (16 flights)

In addition to the stages, a payload rack (multiple manifest flights) and an interstage for the two stage missions are also expended. The payload rack was required

Table 10.4-3. GB Expendable OTV DDT&E Cost

	SMALL OTV SM COST OPTIMIZED DDT&E/DES DDT&E/M	OTV >TIMIZED DDT&E/MFG	LARGE OTV LG COST OPTIM DDT&E/DES DDT	IE OTV OPTIMIZED DDT&E/MFG	LARGE OTV MAN-RATED DDT&E/DES DD	OTV NED DDT&E/MFG
VEHICLE STRUCTURE TANKS	23.67	16.67	(4	22.48	0.36	9.34 A 35
PROFULSION (LESS ENG)	49.81	26.27	13.07	26.43	2,48	24.27
RCS	2.48	4.86	2.84	2.8°	0.44	6.13
AVIONICS Electron bounds	28.50	17.05 a	0.48	8.55 44.45	20.26	26.64
HERMAL CONTROL AEROASSIST				લ	80.0	66.0
ASE 6SE ASSY & C/O		9.54 11.46		12.21 16.99		5,76
HARDWARE SUBTOTAL	437.22	114.41	94.80	161.45	25.66	158.41
SYSTEM ENGR & INTEG		20.87		11.46		4.29
SYS TEST CONDUCT		49.39		14.49		PO . 6
TOOLING % STE		4.99		41.17		20.42
SPARES		9.34				13.56
LIAISON ENGR		3,48		0.54 54		92.3
DATA		5.37		2,13		
LOGISTICS ENGINEERING		9.59	٠	5.01		
sur-rorr subtoral		178,02		93.01		83.95
VEHICLE TOTAL		729.65		349.27		268.02

2LU = Large stages - unmanned 2LM = 2 Large stages - manned

① The 7310 lunar mission was launched into Earth Orbit using 2 CLV flights

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Table 10.4-4 Launch Cost for Expendable OTV Concept

Mission	Payload(Klbs) Up/Down	® Start Weight (KLB)	(d. Stage Type	③ Lift-Off Weight (KLB)	Cost Per Flight (\$M)	Total Flights
GEO Platform	14.6	50.4	S	52.3	32.4	1
Planetary (C3 = 60)	7.5	50.6	7	52.6	32.6	14
Mult. Pld. Del	12/2	43.7	s ·	45.6	28.2	86
Ind. GEO Sat.	7.0	30.9	S	32.8	20.3	-
Ind. GEO Sat.	10.0	38.6	S	40.5	25.1	7
Ind. GEO Sat.	13.2	46.8	S	48.7	30.2	4
Ind. GEO Sat.	13.7	48.1	S	50.0	31.0	-
Ind. GEO Sat.	14.6	50.4	S	52.3	32.4	2
Ind. GEO Sat.	21.8	74.0	7	76.1	47.1	-
Sat. Retrieval	0/10	98.2	วะก	100.6	62.3	2
Manned GEO Sortie	12/10	144.3	2LM	146.8	70.0	16
GEO Shack Unman.	16.7	60.4	-1	62.4	38.6	1
GEO Shack Manned	25.0	81.8	1	83.8	51.9	•
GEO Shack Log.	12/10	134.4	21.0	136.8	70.0	38
Unman. Lunar Orb.	5.0	24.8	S	26.8	16.6	m
Unman. Lun. Surf. Expl.	33.0	87.8	5	7.66	61.7	1
Ottnman. Lun. Surf. D1	73.0	122.0	1	124.0	70.0	4
①Unman. Lun. Surf. D2		100.0	3FD	102.4	63.4	4
DOD GEO Delivery	10.0	38.6	s	40.5	25.1	86
DOD Med. Inclination	10.0	35.9	S	37.8	25.9	131
DOD High Inclination	4.0	15.0	S	16.9	13.1	16

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Table 10.4-5. GB Expendable OTV TFU Cost

LARGE OTV MAN RATED TFU	ବ୍ୟବ୍ୟସ୍ଥାତ ବ	57.76 5.13 0.09 1.78 7.01
LG COST OPTIMIZED TFU	6.56 3.39 5.18 4.00 2.23 7.76 11.49 0.79	46.63 0.07 1.45 5.66
SMALL OTV SM COST OPTIMIZED TFU	4.86 2.48 4.70 4.00 1.92 7.75 3.01 0.62	32.91 2.93 0.05 0.99 36.88
	VEHICLE STRUCTURE TANKS FROPULSION (LESS ENG) MAIN ENGINES RCS AVIONICS ELECTRICAL POWER THERMAL CONTROL AEROASSIST ASE GSE	HAKDWARE SUBTOTAL SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT TOOLING & STE SPAKES LIAISON ENGR DATA LOGISTICS ENGINEERING SUPPORT SUBTOTAL

on 84 flights and had a TFU of \$6M. An interstage was required on 62 flights and had a TFU of \$2.4 million.

10.4.1.4 Ground System Cost

The ground system and associated processing operations for the expendable OTV were described in Section 6.0. The DDT&E cost of \$120 million covers the equipment integration cell. The processing (vehicle preparation and payload mating/checkout) was estimated at \$2.7 million per flight.

10.4.1.5 Mission Control System Cost

The mission control system includes the hardware and software necessary to perform a flight as described in section 7.0. The DDT&E cost of \$623 million covers a 2 step technology approach that allows for a reduced cost per flight. The recurring cost is based on the following:

1995 - 1999

\$3.9 M/flight

• 2000 - 2010

\$3.15 M/flight

10.4.2 Expendable with Aeroassist Payload Return

10.4.2.1 Stage Approach and Groundrules

The stage approach for this concept was described in section 3.6. It's use in performing the various missions is shown in figure 10.4-2. Small and large stages are used for delivery missions and the large stage along with either a payload or crew module aerobrake module is used for roundtrip missions. The unique groundrules and assumptions associated with the concept are presented in table 10.4-6 and -7.

10.4.2.2 Cost Summary

A top level cost breakdown of this expendable with aeroassist payload return concept is presented in table 10.4-8. Further discussion of each system element follows.

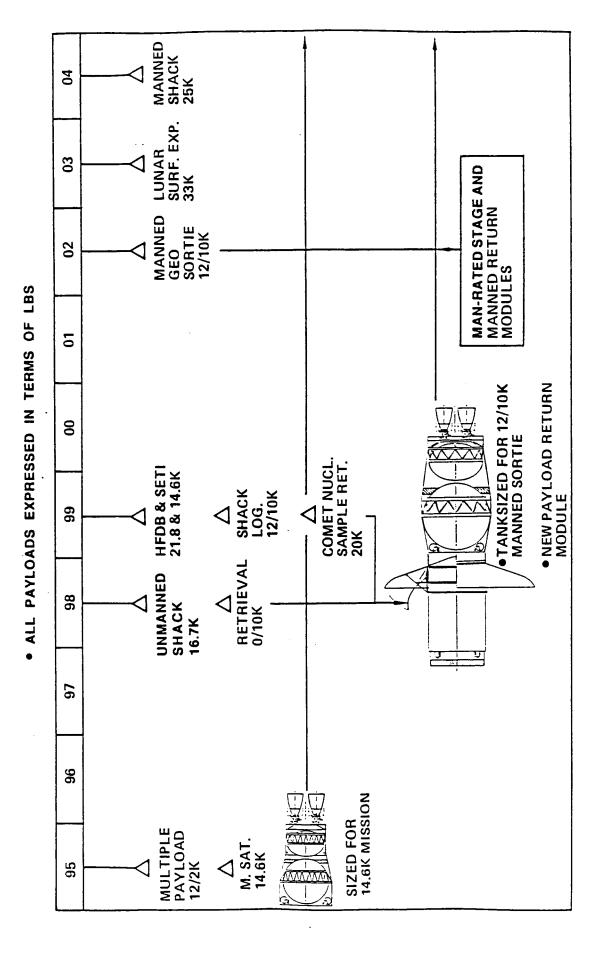


Figure 10.4-2. Expendable OTV Mission Application – Aeroassisted Payload Return

Table 10.4-6. Expendable OTV with Payload Aeroassist Groundrules and Assumptions

SMALL AND LARGE OTY (UNMANNED)

* 80% COMMONALITY IN RCS (MODIFIED PRESSURE SYSTEM).

* 70% COMMONALITY IN FROPULSION SYSTEM (MODIFIED PROPULSION SYSTEM).

* 100% COMMONALITY IN AVIONICS.

* 25% COMMONALITY IN ELECTRICAL POWER (FUEL CELLS WERE USED AS POWER SOURCE PLACE OF BATTERIES).

PAYLOAD RETURN MODULE

* 75% COMMONALITY IN RCS (SIMILAR TO SMALL OTV)

* BO% COMMONALITY IN AVIONICS (SIMILAR TO SMALL OTV)

* BOX COMMONALITY IN ELECTRICAL POWER (SIMILAR COMPONENTS TO SMALL AND LARGE OTV)

Table 10.4-7. Expendable OTV with Payload Aeroassist Groundrules and Assumptions

MAN-RATED AFROASSISTED OTV

- * 100% COMMONALITY IN STRUCTURE.
- * 100% COMMONALITY IN THERMAL PROTECTION.
- 95% COMMONALITY IN RCS (ADDED THRUSTERS).
- * 90% COMMONALITY IN FROPULSION SYSTEM (ADDED REDUNDANCY).
- 50% COMMONALITY IN AVIONICS (ADDED SYSTEM REDUNDANCY AND INTERNALLY REDUNDANT DMU'S).
- 90% COMMONALITY IN ELECTRICAL FOWER (ADDED REDUNDANCY).

AEROASSIST MODULE FOR CREW MODULE RETURN

- 75% COMMONALITY IN STRUCTURE (SIMILAR TO PAYLOAD MODULE)
- * 75% COMMONALITY IN RCS (ADDED THRUSTERS; MODIFIED PRESSURE SYSTEM)
- * 100% COMMONALITY IN AVIONICS (SAME COMPONENTS AS PAYLOAD MODULE AND LARGE OTV)
- * 100% COMMONALITY IN ELECTRICAL POWER (SAME COMPONENTS AS PAYLOAD MODULE AND LARGE ()TV)
- * 15% COMMONALITY IN RECOVERY SYSTEM (COMMON STRUCTURAL COMPONENTS WITH PAYLOAD MODULE)

Table 10.4-8 Expendable OTV with Aeroassist Module Cost Summary

DTT&E (Non-Recurring)		2,511
OTV	1,616	
Mission Control	775	
Ground System	120	•
Production		39
P/L Module	39	
Operations		22,521
Launch (CLV)	13,667	
Mission Control	1,601	
OTV Processing	1,174	
Expend/Amortize Hrdw	5,946	
Down-Cargo	132	
	Total LCC	25,071
	Discounted	6,248

10.4.2.3 OTV Cost

The DDT&E cost for the OTV portion of this concept is estimated at \$1,616 million. The cost breakdown related to the stage systems is presented in table 10.4-9. The small stage requires \$730 million; development of the large stage and payload aeroassist module require an additional \$540 million; and man-rating the large stage along with development of a crew module aeroassist module contributes \$345 million.

The production cost of \$39 million relates to a second payload aerobrake module. One unit is provided in the DDT&E and no additional crew module aerobrake modules are required beyond that provided in the DDT&E.

The OTV operations cost is defined to include the launch, expendable hardware, and down cargo. The launch cost contribution is \$13,667 million. The cost per mission type is presented in table 10.4-10. The full load point for all GEO destination missions was 113K lbm when using the CLV, 102K lbm for the medium inclination DOD missions and 90K lbm for the high inclination missions. The expendable hardware cost for the concept is \$5,946 million. The TFU cost for the major systems is presented in table 10.4-11. The number of units required for each system element is as follows:

Table 10.4-9. GB Expendable with Payload Aeroassist DDT&E Cost

	SMALL O COST OPTI DDT&E/DES	TV NIZED DDT&E/MFG	COST OPT/PI DDT&E/DES	OTV L KET MOD DDT&E/MFG	MAN-RATED/CREWI DDT&E/DES	DIV MODVRET MOD DDT&E/MFG
EXPENDABLE VEHICLE STRUCTURE TANKS PROPULSION (LESS ENG) MAIN ENGINES KCS AVIONICS ELECTRICAL POWER THERMAL CONTROL	23.67 23.67 300.00 300.00 2.48 2.48 20.30 20.30	16.67 10.52 26.27 26.27 8.00 4.86 17.05 1.76	27.13 12.59 12.59 2.98 39.84 5.55	24.25 13.79 27.65 8.00 6.09 8.57 44.52	0.38 0.12 3.85 0.55 4.59	84 2 2 2 2 2 4 2 3 2 3 2 3 2 3 3 3 3 3 3
EXPENDABLE SUBTOTAL	437.22	93.42	97.48	133.84	29.82	136.52
BRAKE MODULE STRUCTURE RCS RVIONICS ELECTRICAL POWER REUSABLE AEROASSIST			1.02 3.04 3.085 3.27	1,44 7,18 0,64 14,91 35,70	0.18 3.13 0.28 1.68	1.18 8.85 0.79 13.85 29.88
BRAKE SUBTOTAL	00.0	0.00	67.09	59.8	16.6	4.5
ASE GSE ASSY & C/O HARDWARF SHRTOTA!	437.22	9.54	164.77	18.40 24.92 237.02	46.50	6.08 17.11 214.25
25 10 25 11 11	4 - - -	CRC40WRD I	•	22.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.		130 7 2 2 2 3 3 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
SUPPORT SUBTOTAL		178.0	•	38.88		84.58
VEHICLE TOTAL COMBINED TOTAL = \$1,616M		729.65		540.65		345.33

Table 10.4-10 Launch Cost for Expendable with Payload Aeroassist

GEO Platform 14.6 Planetary (C3 = 60) 7.5 Mult. Pld. Del 12/2 Ind. GEO Sat. 7.0 Ind. GEO Sat. 13.2 Ind. GEO Sat. 13.7 Ind. GEO Sat. 13.7 Ind. GEO Sat. 21.8 Sat. Retrieval 0/10 Manned GEO Sortie 12/10 GEO Shack Unman. 16.7 GEO Shack Log. 12/10 Unman. Lunar Orb. 5.0	50.4 55.4 43.7 30.9 38.6 46.8 48.1	s -	52.3		
=60) Sortie 1 anned 1 r Orb.	55.4 43.7 30.9 38.6 46.8 48.1	_		32.4	1
Sortie 1 nman. anned 1 r Orb.	43.7 30.9 38.6 46.8 48.1	ı	57.6	35.7	14
Sortie 1 anned 1 r Orb.	30.9 38.6 46.8 48.1 50.4	S	45.6	28.2	98
Sortie 1 nman. anned 1 r Orb.	38.6 46.8 48.1 50.4	s	32.8	20.3	1
Sortie 1 nman. anned 1 sg. 1	46.8	S	40.5	25.1	2
Sortie 1 nman. anned 1	48.1	S	48.7	30.2	4
Sortie 1 nman. anned 1 og. 1	50.4	s	50.0	31.0	-
Sortie 1 nman. lanned 1 og. 1		S.	· 52.3	32.4	2
Sortie nman. anned og.	9.77	7	7.67	49.4	1
	70.1	1	72.3	44.8	2
	106.3	ΓM	108.5	67.2	16
	63.9		66.1	40.9	+
	85.3	7	87.5	54.2	-
	101.6	1	103.8	64.3	38
	24.8	S .	26.7	16.5	3
Unman. Lun. Surf. Expl. 33.0	101.2	J	103.4	64.1	
①Unman. Lun. Surf. D1 73.0	144.0	7	146.1	70.0	4
①Unman. Lun. Surf. D2 -	73.0	7	75.1	46.5	4
DOD GEO Delivery 10.0	38.6	S	40.5	25.1	86
DOD Med. Inclination 10.0	35.9	S	37.8	25.9	131
DOD High Inclination 4.0	15.0	8	16.9	13.1	16

① The 7310 lunar mission divided into 2 CLV launches
② OTV & Payload
③ OTV & Payload & ASE

LM = Large Manned L = Large

 \odot S = Small

Table 10.4-11. GB Expendable with Paylaod Aeroassist TFU Cost

LARGE 0TV MAN-RATED/CREW MOD/RET MOD TFU		51.91	0W-04	· S	10.6	95.	B.4 0.1	11.58	107.01
LARGE OTV COST OPT/PL RET	2.35 2.35 2.35 2.35 0.57 0.52	42.54	0.45 3.05 10.27 9.46	. 48	9.40	3.4	7.40 0.14	10.15	93.57
SMALL OTV COST OPTIMIZED TFU	4044-rm0	29.33		0.00	3, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,	2.9	2.9	3.97	36.88
	EXPENDABLE VEHICLE STRUCTURE TANKS FROPULSION (LESS ENG) MAIN ENGINES RCS AVIONICS ELECTRICAL POWER THERMAL CONTROL AEROASSIST	EXPENDABLE SUBTOTAL	BRAKE MODULE STRUCTURE RCS AVIONICS ELECTRICAL POWER AEROASSIST	BRAKE SUBTOTAL	6SE ASSY & C/D	HARDWARE SUBTOTAL	SYSTEM ENGR & INTEG SOFTWARE SYS TEST CONDUCT TOOLING & STE SPARES LIAISON ENGR DATA LOGISTICS	SUPPORT SUBTOTAL	VEHICLE TOTAL

	<u>Element</u>	<u>Units</u>	<u>TFU (\$M)</u>
•	Small Stage	344	36.9
•	Large Stage (unmanned)	66	51.9
•	Large Stage (manned)	18	63.7
•	P/L Aerobrake	40	21.8
•	Crew Module Aerobrake	16	8.4

The expendable hardware cost also includes an average contribution of \$0.5M per flight for payload racks and interstages.

The down cargo cost of \$132 million is based on an annual cost of \$44 million for 1999-2001. Other years did not have down cargo or a cost impact.

10.4.2.4 Ground System Cost

The ground system and associated processing operations for the expendable OTV were described in section 6.0. The DDT&E cost of \$120 million covers the equipment integration cell. The processing (vehicle preparation and payload mating/checkout) was estimated at \$2.75 million per flight.

10.4.2.5 Mission Control System Cost

The mission control system includes the hardware and software necessary to perform a flight as described in section 7.0. The DDT&E cost of \$775 million covers a 2-step technology approach that allows for a reduced cost per flight. The recurring cost is based on the following:

•	1995 - 1999	\$3.9 M/flight
•	2000 - 2010	\$3.65 M/flight

11.0 ENVIRONMENTAL ANALYSIS

11.1 INTRODUCTION

As discussed earlier in this document, the Rev. 9 mission model and use of a CLV has lead to the conclusion that an expendable OTV is cost optimum. The fact that the vehicle is expended after each mission is the major departure from the results of the Phase 1 conclusions insofar as potential environmental effects are concerned. In this regard, there are two disposal types: disposal in high orbits and beyond, which will be referred to here as space disposal; and disposal into the Earth's atmosphere.

11.2 SPACE DISPOSAL

The majority of the OTV missions result in space disposal. These include high Earth orbit, GEO delivery, translunar, and interplanetary missions. OTVs used for GEO delivery, are boosted to a circular orbit at an altitude of GEO + 850 nm after payload release. This orbit precludes interference with the spacecraft at GEO and assures a very long orbital lifetime. OTVs used to place payloads in high Earth orbit or on translunar trajectories are left in either a high Earth orbit (below or above GEO) or targeted to impact the moon (as was done with the S-IVB stages on the Apollo program). In either case, the spent stages offer no threat in terms of Earth impact. OTVs used to place payloads on interplanetary trajectories have attained earth escape velocity and are left in solar orbit after payload separation. Residual propellant will be used to assure that this orbit does no cross the Earth's orbit. Given planetary and comet perturbations, this does not reduce Earth return probability to zero but makes it quite small.

Based on the foregoing, OTV disposal in space (as defined above) is judged to require no environmental analysis.

11.3 EARTH DISPOSAL

Missions that result in a return to LEO (manned missions, satellite retrieval, etc.) are placed on an atmosphere entry trajectory after payload delivery. These few missions will result in a relatively small percentage of the vehicle surviving the heat of entry to impact the Earth's surface. While the analysis of how much material will survive and the size of the resulting debris footprint is beyond the scope of this study, the entry trajectory would be tailored to place this footprint in remote ocean areas.

The materials that are vaporized during OTV entry consist primarily of aluminum, graphite/epoxy, steel, and propellant residuals. The basic elements involved are, for the

most part, the constituents of meteors that are also vaporized in the atmosphere. The vaporization process is substantially complete above 100,000 ft and is spread over a large area. The quantities involved are minor compared to the meteor flux.

An exhaustive and quantitative analysis of the constituents is beyond the scope of this study. A qualitative analysis indicates no environmental concerns.

11.4 CONCLUSIONS

There exist no environmental concerns associated with the use of an expendable OTV as defined in this study for the mission scenarios specified.

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12.0 RECOMMENDED CONCEPT DEFINITION

This section summarizes the key features of the new technology expendable OTV which was the recommended concept resulting from the trade studies described in section 9.0. It should be noted, however, that a new technology expendable with aeroassist payload return provided essentially the same cost and would have been recommended with more return missions.

12.1 SYSTEM APPLICATION AND DESCRIPTION

The time-phased application of the new technology expendable OTV in satisfying the Rev. 9, Scenario 2 mission model is shown in figure 12.1-1. The initial stage is sized for the 14.6K lbm delivery mission to GEO and is used throughout the mission model. When more demanding missions occur in 1998 a new large version of the stage is introduced. The size of the larger stage is determined by the plan to use two of these stages to perform the most demanding mission which is the manned sortie to GEO.

Configuration. The key configuration characteristics of the small and large stages are presented in figure 12.1-2 and 12.1-3, respectively. The small stage has a start burn weight of 50.5K lbm when delivering a 14.6K lbm payload to GEO. For less demanding missions the stage is off-loaded. The large vehicle is sized to serve as one of two stages used to perform the manned GEO sortie mission. As such, an individual stage is capable of delivering 33K lbm to GEO. When flown in a two stage mode, 12K lbm can be transported to GEO and 10K lbm returned to LEO. The launch weight of this dual stage system provides a small margin relative to the launch vehicle lift capability. Subsystems for both stages (small and large) are essentially the same.

Structures. The body shell uses a graphite/epoxy honeycomb sandwich design. Major rings are located at each tank support location as well as at the payload interface and ASE interface. The avionics/equipment support ring consist of GR/EP structure with aluminum doors for mounting of avionics and electrical power components. The LH2 and LO2 tanks are all-welded 2219-T87 aluminum and are supported by struts within the external body shell. Both tanks have zero-g start baskets for propellant acquisition and are sized for an oxidizer-to-fuel mixture ratio of 6:1. The propellant tank shells are designed to permit room temperature proof testing to ensure service life requirements. The hydrogen tank has spherical heads and the oxygen tank has .707 elliptical heads.

Main Propulsion System. The main engines are advanced LO2/LH2 expander cycle space engines, with retractable nozzles. The engines are rated at a maximum vacuum

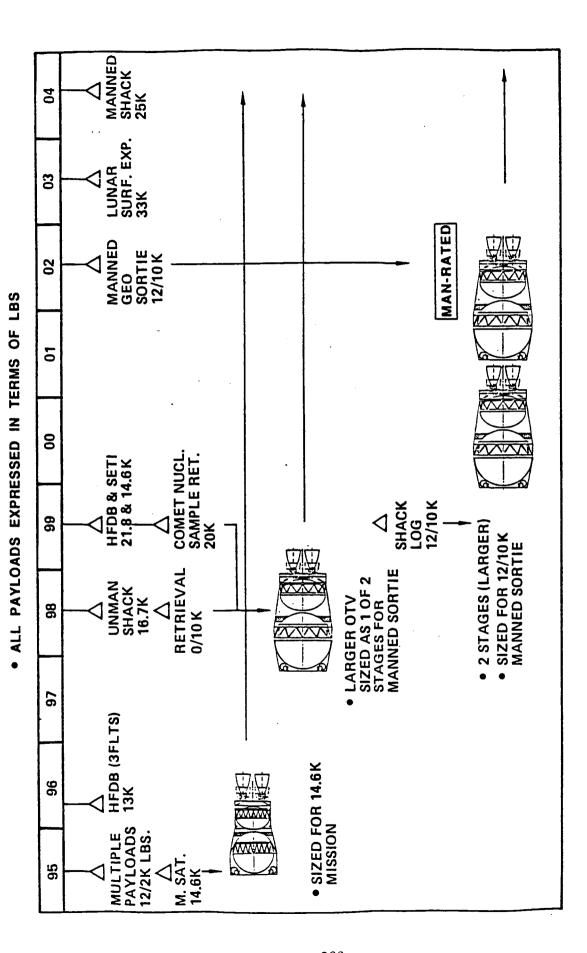
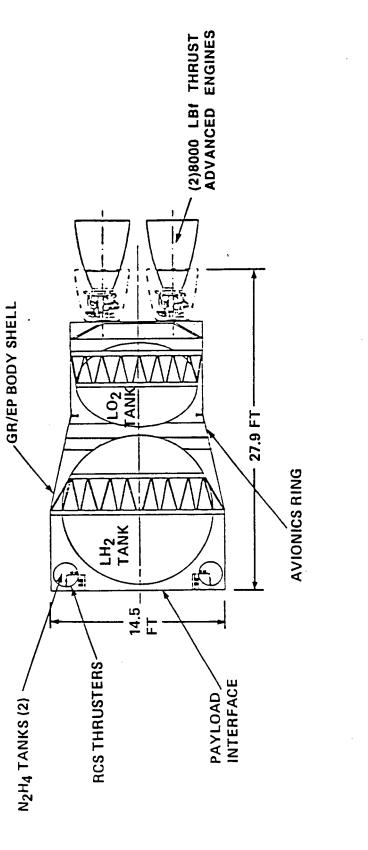
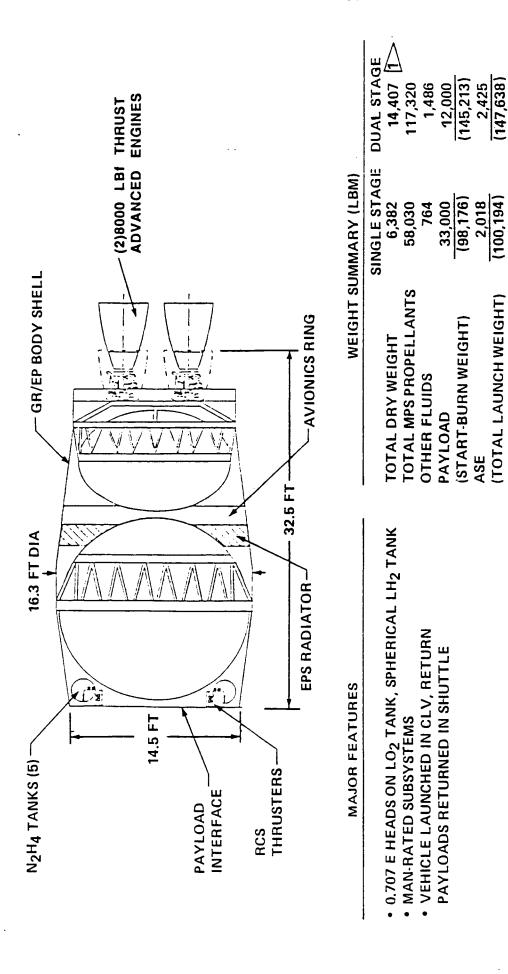


Figure 12.1-1. Expendable OTV Mission Application



WEIGHT SUMMARY (LBM)	ANTS.	1,910 EIGHT) (52,450)
WEIGHT	TOTAL DRY WEIGHT TOTAL MPS PROPELLANTS OTHER FLUIDS PAYLOAD (START-BURN WEIGHT)	ASE (TOTAL LAUNCH WEIGHT)
MAJOR FEATURES	 0.707 E HEADS ON LO2 TANK, SPHERICAL LH2 TANK COST-OPTIMUM REDUNDANCY VEHICLE LAUNCHED IN CLV, NOT RETURNED POWER SOURCE IS SILVER-ZINC BATTERIES 	

Figure 12.1-2. Small GB Expendable OTV Configuration



1 INCLUDES 2 STAGES AND INTERSTAGE

Figure 12.1-3. Large GB Expendable OTV (AII-Propulsive (P/L Return) Configuration

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thrust of 8000 lbf each and provide a specific impulse of 483 sec at an oxidizer-to-fuel mixture ratio of 6:1. Thrust vector control is provided by two electromechanical ballscrew linear actuators for each engine, equipped with redundant electric motor drives. Pressurization for the main propellant tanks is autogenous and consists of plumbing for delivery of pressurization gases (GH2, GO2) from the engine-mounted bleed ports to the tanks. Propellant feed lines are of aluminum and include bellows expansion joints to compensate for thermal expansion and engine gimballing. The propellant fill/drain/dump system includes rise-off disconnects for LH2 and LO2 at the stage/ASE interface. Two separate tank vent/relief systems are provided. All main valves in the propellant feed system, and fill/drain/dump system are electrically actuated.

Reaction Control System. The RCS uses hydrazine monopropellant, pressurized by nitrogen gas supplied from a separate gas bottle. Sixteen thrusters are located in four modules, and use a catalytic decomposition gas generator to produce 25 lb thrust each with a 320 psia supply pressure. Pressurant is supplied by a 3500 psia stored gas system, using a KEVLAR-overwrapped storage bottle. Propellant storage consists of 22 in diameter titanium tanks with expulsion diaphragms each having a storage capacity of 195 lb of hydrazine.

Thermal Control. The passive thermal control techniques include insulation blankets, thermal control coatings, and selected radiative surfaces. The thickness of the aluminum used for the avionics ring assembly is controlled to provide for proper heat flow from internally mounted components and its exterior surface is covered with flexible optical solar reflector (FOSR) to provide the radiative surface. Electrical heaters are provided for RCS components and avionics equipment as required. The LH2 and LO2 tanks are insulated with MLI. The MLI consists of layers of doubly aluminized kapton with a dacron net spacer. Fifty layers of MLI are used on the LO2 tank and 34 on the LH2 tank. The MLI wrapped tanks are enclosed within purge barriers which are purged with dry gas (helium for the LH2 tank and nitrogen for the LO2 tank) prior to launch.

Guidance and Navigation. The guidance and navigation subsystem consists of an internally redundant laser gyro inertial reference unit (IRU) and a star tracker. The IRU provides angular rate and linear acceleration data. Attitude is initialized and updated by the star tracker.

Communications and Data Handling. The communications subsystem consists of redundant radio frequency (RF) links that are NASA STDN/TDRS compatible. Deployable pairs of antenna pods are diametrically located in the equipment ring

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assembly. Each RF link contains a 20W S-band power amplifier and a NASA STDN/TDRS transponder.

The data handling subsystem consists of four advanced integrated data management units, each containing its own signal processing and conditioning units, and instrumentation for status monitoring of stage subsystems. The instrumentation subsystem provides for monitoring of main propellant tank loading and usage.

Electrical Power. The electrical power source for the small stage is silver-zinc batteries because the mission duration is less than one day. The large stage when used for manned sorties would use LO₂/LH₂ fuel cells. Redundancy is provided in the power conversion and distribution units.

12.2 PROGAMMATICS

The development schedule for the new technology small expendable cryo OTV is estimated to require 6 years. The pacing item will be the advanced main engine. A three year development time is allocated for the large unmanned stage because of its similarity with the small stage. Three years has also been allowed to achieve manrated status of the large stage. The average production rate is 26 stages per year.

The total non-recurring cost for this concept is \$2,091 million. The vehicle contribution being \$1,348 million and the remainder related to the necessary mission control and ground operations systems. (Note: the ground and mission operations cost were not defined in the Phase I analysis). The total recurring cost for 442 OTV flights is \$23,308 million. Launch cost contributes nearly \$14,000 million while the production cost of the expendable stages adds \$6,700 million.

12.3 TECHNOLOGY NEEDS

For the new technology expendable OTV, the most significant technology needs are the advanced engine and avionics. The advanced engine is cost optimum as well as necessary for performance reasons. The assumed Isp of 483 sec will require development work to achieve high chamber pressures (≥ 1500 psia) and high expansion ratios (≥ 1000) Long life and maintenance features are not important when used in an expendable mode. The most significant needs in avionics deals with data management systems. In this area, improvements are necessary in redundancy management techniques such as voting schemes and functional partioning. Reductions are also required in weight, power, and packaging density.

Should payload return by aeroassist means be selected for growth missions then improvements are necessary in the areas of the accuracy of aerothermal and

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aerodynamic predictions, thermal protection system capability, and development of guidance algorithms. An aeroassist fight experiment should be performed to demonstrate the concept.

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13.0 SUMMARY AND CONCLUDING REMARKS

The most significant change in the prior findings deals with the basing mode and the reusability of the OTV as brought about by a new unmanned cargo launch vehicle (150 K lbm capability) and larger OTV mission models (Rev. 8: 250 to Rev. 9: flights). The least cost system for the above conditions is a new technology expendable cryogenic OTV. This approach provided a 28% discounted cost advantage over fully or partially reusable GB or SB OTV concepts. The principal areas contributing to the cost advantage over the reusable GB OTV concept is less launch cost when using a user's charge approach and no earth return penalty. The launch savings occurs because 85% of the missions are delivery only. On these missions, the new expendable OTV has an average launch weight savings of 30,000 lbm relative to a reusable OTV because it does not require a GEO deorbit burn (6250 fps) or an aeroassist device (approximately 2500 lbm) to be used for the LEO capture maneuver. Cost savings relative to a SB OTV only mode is in DDT&E because of a smaller stage and no orbital support is required. Recurring cost savings occur in the OTV processing area and orbital support. summary, the new expendable concept provides least cost because the large savings in DDT&E, launch, no recovery, and processing far exceed the expendable hardware cost.

The selected expendable OTV program would begin with a stage sized for delivery of 15K lbm to GEO. When more demanding missions (including roundtrip) occur, an all-propulsive mode can be maintained by using multiple stages or an alternate mode could employ an aeroassist module to only return the payloads.

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